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Turbulence and the Boundary Layer

HUGH L. DRYDEN, *National Bureau of Standards*

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Introduction

THE Wright Brothers Lecture Committee has given me a very great privilege as well as a great responsibility in inviting me to deliver the second Wright Brothers Lecture. It is a great privilege because every worker in the aeronautical sciences covets the opportunity to do honor to Wilbur and Orville Wright. It is a great responsibility because of the high standard for this important aeronautical occasion set last year by Professor B. Melvill Jones of Cambridge University, England, in the inaugural lecture.[1] The maintenance of that standard will bring renown to the name of the Institute of the Aeronautical Sciences and will most appropriately honor the men who first brought to fruition the aims of all the aeronautical sciences.

That first successful flight of man in a power-driven aircraft just 35 years ago today was, as is well known to this audience, the culmination of a carefully planned scientific study of the problems of flight. That study included flight experiments on kites and gliders, which showed discrepancies in the existing scientific data, and wind-tunnel experiments on some 200 airfoils, which furnished the data on which the design of the wings and propeller of the first man-carrying airplane was based. The Wright brothers were also experts in the design of engines and structures, and well acquainted with the properties of materials. Building on their secure foundation, the members of this Institute have revolutionized not only the means of transportation, but even the habits of thought of mankind. What method of honoring the pioneers could be better than to give our efforts to advancing the science and art which they established.

In the inaugural lecture, Professor Jones presented a very clear picture of the practical importance to the airplane designer of an understanding of the nature of the flow in boundary layers, those relatively thin layers near the surfaces of bodies moving through fluids in which the speed falls rapidly because of the predominant action of internal friction. That lecture dealt in particular with the factors controlling the transition from laminar to eddying flow and with Professor Jones' most interesting and significant studies of the boundary layer on airplanes in flight. The present lecture is in a sense parallel to that of Professor Jones' in that it deals with investigations of the same problem in wind tunnels, for it is still profitable to conduct research both in wind tunnels and in flight as did the Wright brothers.

Wind tunnels are constructed for the purpose of creating a relative motion between the air and the model which is the same as that between the full scale aircraft and the air. For purposes of preliminary design the full scale aircraft is assumed to move forward at a uniform speed into still air. Hence the artificial wind in the wind tunnel must be uniform and steady in speed and direction. The history of the develop-

ment of wind tunnels from the wind tunnel of E. H. Wenham in 1871, that of H. Philipps in 1884, those of Mach, Irminger and Vogt, Renard, Maxim, LaCour, and Marey in the 1890's, and those of Zahm, the Wright brothers, Stanton, Crocco, Riabouchinsky, and Rateau in the 1900's to the wind tunnels of Prandtl and Eiffel in 1908 and 1909, and the large number constructed since that time is the record of steady progress toward that ideal. Yet the ideal has never been attained. There is always present some small fluctuation of the air speed with time at relatively high frequency which introduces a new variable, turbulence. This variable often has important effects on the measurements.

For some ten years my colleagues and I at the National Bureau of Standards have been studying methods of accurately measuring turbulence in wind tunnels and attempting to gain an understanding of its effects in wind-tunnel measurements. This lecture constitutes a general report on the investigation to date. The work has been conducted in cooperation and with the financial assistance of the National Advisory Committee for Aeronautics, and acknowledgment is made to Dr. George W. Lewis, Director of Research of the Committee, for permission to make use of some information which has not yet been published by the Committee.

While the effects of turbulence were first discovered by Osborne Reynolds[2] in his study of the flow of water in pipes, the story of wind-tunnel turbulence properly begins with Eiffel's measurement of the drag of a sphere in his newly constructed wind tunnel. In 1911, Eiffel[3] published his result which in our modern terminology corresponds to a drag coefficient of 0.18. A year later, Föppl[4] of the Aerodynamic Institute at Göttingen stated that Eiffel's published value was obviously in error, probably a misprint, and that the true value was 0.44, or nearly three times as great. Further experimental study by Eiffel[5] and by Wieselsberger[6] and theoretical studies by Prandtl[7] led to a reasonable explanation of the discrepancy. Eiffel's result could be obtained in the Göttingen wind tunnel by producing disturbances in the flow ahead of the sphere by the use of wire screens or by disturbing the flow in the boundary layer of the sphere by placing a wire ring on the surface. It was inferred that Eiffel's tunnel was more turbulent than the Göttingen tunnel and that the effect of the turbulence was to cause the boundary layer flow to change from a smooth laminar flow to an eddying flow, which in turn caused a more vigorous scouring away of the wake and delayed the separation of the flow from the surface. Prandtl suggested a method of classifying wind tunnels in order of magnitude of turbulence in terms of the curves of drag coefficient of a sphere, the marked decrease in drag coefficient occurring at higher Reynolds Numbers in streams of lower turbulence.

Turbulence was soon found to affect other types of measurements. Thus in 1923 the National Physical Laboratory began the circulation of two airship models for comparative tests in a large number of the wind tunnels of the world. The result in the United States wind tunnels[8] showed variations of 50 percent from a mean value. By 1929, we had succeeded in making quantitative measurements of turbulence by the aid of the hot wire anemometer and were able to show definitely that the drag coefficients of spheres and airship models did vary systematically with the measured turbulence. In the report of that work[9] it was predicted that much smaller effects of turbulence might be observed on airfoils and the general nature of the expected effects was described. These effects, found in the experiments of Millikan and Klein[10] at the California Institute of Technology, explained discrepancies between measurements of maximum lift coefficients in several wind tunnels.

These examples suffice to illustrate the widespread nature of the influence of turbulence on measurements made in wind tunnels. The drag of a sphere may vary by a factor of 4, the drag of an airship model by a factor of 2, and the maximum lift of an airfoil by a factor of 1.3 in airstreams of different wind tunnels at the same air speed, if the turbulence is sufficiently different. This result does not mean that wind tunnels are useless to the designer. It does, however, emphasize that the turbulence characteristics of the wind tunnel need to be known and taken into account in the interpretation of measurements. It is also obvious that the turbulence characteristics of the atmosphere need to be studied. We have to do essentially with a new independent variable whose effects are as important as those of Reynolds Number and in many ways similar to those of Reynolds Number as discussed elsewhere.[11]

The Concept of Turbulence

It is desirable that the designer of aircraft should have as clear a picture as can be obtained of the meaning of the word turbulence as applied to flow in wind tunnels. Unfortunately, the word is used in many senses and is often associated with advanced mathematical manipulations. It is stated by von Kármán[12] that G. I. Taylor once gave a lecture on turbulence before the Royal Meteorological Society without a single mathematical symbol, an accomplishment characterized by the president of the society as "turbulence without tears." This is a magnificent ideal and I believe it can be approximated more closely for wind-tunnel turbulence than for the fully developed turbulence associated with velocity gradients in what I prefer to call "eddying flow" to distinguish it from the simple approximately isotropic turbulence found in modern wind tunnels.

There should be little more difficulty in forming a satisfactory mental picture of isotropic turbulence than in forming a satisfactory concept of the motion of the

molecules of a gas. The picture cannot be a static one. Most of us readily visualize innumerable small particles darting to and fro in an irregular manner, and realize that while the motions of individual particles are of little interest, certain average properties such as the mean velocity and the mean free path can be used to characterize the statistical behavior of the cloud of particles. We have no difficulty in conceiving the mean velocity as being the same in all directions.

Turbulence can be mentally pictured in similar fashion except that the medium is continuous and the moving masses of fluid are much larger than molecules. The turbulence in a wind tunnel may be visualized as a cloud of many small air masses with ill-defined boundaries moving to and fro in an irregular manner, and riding along on the wind-tunnel air stream. In this concept the observer pictures himself as moving with the air stream at its mean speed.

Some people find it more helpful to observe the flow from a position of rest and to think of turbulence as analogous to ripples on the surface of a flowing stream of water or as analogous to the gusts of the natural wind. If this concept is used, it must be remembered that the ripples or gusts in wind tunnels are very minute and would be imperceptible to human senses even if the frequency were sufficiently low to permit the muscular sense to respond.

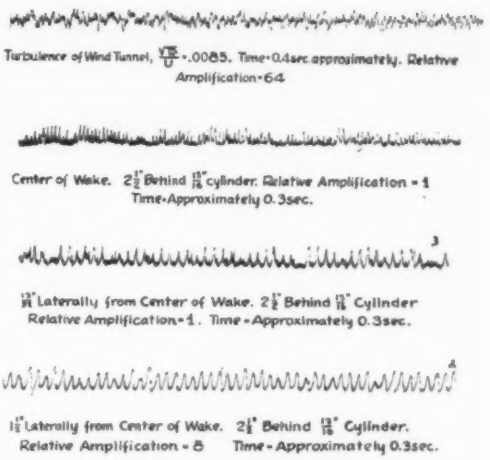
Turbulence of Wind Tunnel, $\frac{\sqrt{u^2}}{U}$ = .0085. Time = 0.4 sec approximately. Relative Amplification = 64
Center of Wake. 2½" Behind ¹³/₁₆" cylinder. Relative Amplification = 1
Time = Approximately 0.3 sec.
¹³/₁₆" Laterally from Center of Wake. 2½" Behind ¹³/₁₆" Cylinder
Relative Amplification = 1. Time = Approximately 0.3 sec.
1½" Laterally from Center of Wake. 2½" Behind ¹³/₁₆" Cylinder.
Relative Amplification = 8 Time = Approximately 0.3 sec.
Air Speed = Approx. 60 ft/sec.
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FIG. 1. Oscillograms of speed fluctuations in wind tunnel turbulence and in the vortex street behind a cylinder.

The second and third records are considerably distorted because the electric current in the amplifier output is not proportional to the speed fluctuation for the extremely large fluctuations near the center of the wake. Note the frequency doubling at the center of the wake and the regular character of the records of the vortex street as compared with the record of wind-tunnel turbulence.

In wind tunnel air streams the root-mean-square speed fluctuation is usually less than 2 percent, in most modern tunnels less than $^1/_2$ percent of the mean speed. At a mean speed of 200 ft. per sec. this corresponds to fluctuations of the order of 1 ft. per sec. When observing smoke particles in such a stream, the resulting irregular motions are hard to detect, the inclination to the mean direction of flow varying by 1° or less.

Turbulence, then, means fluctuation of the speed at any point with time. However, all fluctuations with time are not, or at least should not be termed, turbulence. Fig. 1 shows oscillograph records proportional to velocity fluctuations in the vortex street behind a cylinder and in the turbulence of a wind-tunnel air stream. The fluctuations of turbulence are irregular. There is no definite periodicity with time and the number of times during a large number of fluctuations that a given magnitude is reached varies with the magnitude in a chance fashion corresponding to the so-called Gaussian distribution.

By various methods it has been ascertained that the fluctuations are also irregular in direction and that in many wind tunnels the mean value of the fluctuation of the velocity component in any direction is independent of the particular direction studied. In this respect the motion is similar to the motion of molecules. The turbulence is said to be isotropic.

Turbulence in a wind tunnel is to be carefully distinguished from pulsations of the wind-tunnel stream as a whole or from the relative motions produced by vibration of the body whose aerodynamic characteristics are under study. It is well known that in most wind tunnels there are very slow fluctuations of speed caused by variations in the speed of the wind-tunnel fan. These do not constitute turbulence. There are usually somewhat faster fluctuations still visible on the usual manometer which are associated with pulsations of the stream as a whole. These also should not be considered as turbulence. However, no sharp demarcation can be made. Some experimenters regard all fluctuations of frequency greater than 10 or 20 per sec. as turbulence. We have designed our equipment to respond to all fluctuations whose frequencies are greater than 1 or 2 per sec. In reality, the definition of turbulence is necessarily arbitrary and the most useful definition depends on the purpose of the study.

If instruments of suitable size could be constructed, the motions of individual molecules could be studied. (An approach is made in the study of the Brownian movement of very small particles.) The fluctuations would be exceedingly rapid, 5×10^9 per sec. With an instrument not more than 1 mm. in greatest dimension, fluctuations of frequencies of the order of 10^4 per sec. could be studied in streams of a mean speed of 40 ft. per sec. With an instrument about 3 ft. in greatest dimension, fluctuations of a frequency of the order of 13 per sec. could be studied in a stream of the same speed, assuming that the inertia of the instrument was sufficiently low. There is thus an upper frequency limit fixed by the limitations of the available instruments. By the suitable selection of an instrument the upper frequency can be made sufficiently high to re-

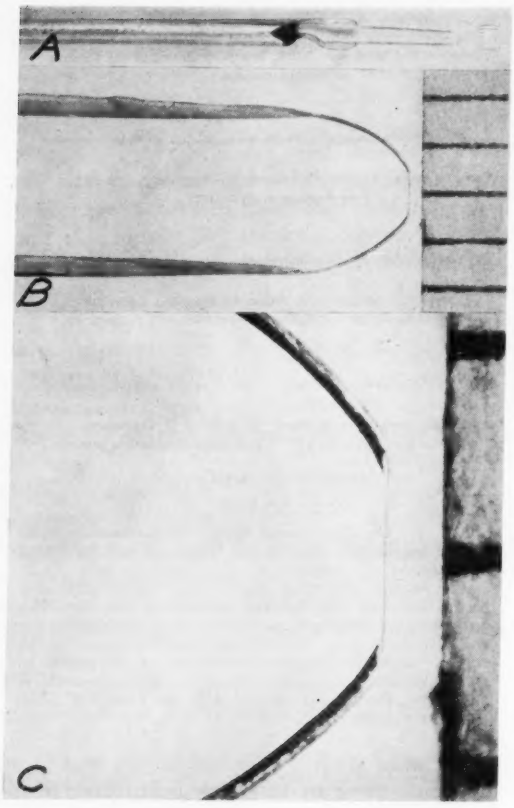


FIG. 2. Hot wire anemometer. The scale shown is a millimeter scale.
A. The complete exploring head.
B. The sewing needles which form the tips of the supporting prongs. A loop of Wollaston wire is soldered to the needles.
C. The loop of Wollaston wire. The coating is etched away for a length of about 1 mm. leaving the bare platinum wire about 0.008 mm. (0.0003 in.) in diameter.

produce fluctuations produced by turbulence in which the air masses are as small as 1 mm. if the information is required by the study at hand.

At the other end of the range, the lowest frequency considered should be related to the scale of the apparatus in which the flow occurs and to the speed of flow. In studying the general circulation of the atmosphere, for example, the mean motion is taken as the average over a period of years and the motions in the lows and highs of the daily weather map with periods of several days constitute the turbulence. The designer concerned with gust loads considers the mean motion as the average over several minutes and the fluctuations with periods of several seconds as the turbulence. The wind-tunnel operator considers the average over a few minutes as the mean motion and the fluctuations occurring as many times per second as the superposed turbulence.

In general, this sequence corresponds to a progressive decrease in the scale of the fluctuations, an increase in their frequency and decrease in their intensity. Dimensional reasons could be advanced for selecting the lower limit such that the product of frequency by the scale of the fluctuations that is of interest in the particular problem, divided by mean speed, is constant. However, as stated previously, the lower limit for studies of wind-tunnel turbulence has usually been fixed arbitrarily at 1 or 2 cycles per sec.

The turbulence in a wind-tunnel air stream is usually approximately isotropic. That which develops in the flow near and behind an object placed in the stream is not isotropic; it exhibits a definite correlation between the fluctuations of the velocity components along and at right angles to the direction of mean flow. As a result of this correlation there is a transfer of momentum across the direction of mean flow.

The turbulence in a wind tunnel arises from the wake of obstacles in the flow upstream from the working section, *i.e.*, guide vanes or honeycomb. The non-isotropic turbulence of considerable intensity in the wake of the upstream obstacles becomes more and more nearly isotropic as its intensity diminishes with increasing distance from its source.

While isotropic turbulence is merely the limiting case in which the correlation between the components is zero and there is no net transfer of momentum between adjoining layers, it is in the interest of clarity to make a distinction between isotropic and non-isotropic turbulence. The type of flow in which there is correlation between the components has long been known as turbulent flow, and the turbulence within it as "fully-developed" turbulence in contrast to the "initial" turbulence of the wind-tunnel stream. The adjectives are usually omitted very early in the discussion, and confusion arises by references to the effect of turbulence on the origin of turbulence. For this reason it is suggested that different words be used, and the term "eddying flow" will be used hereafter in this paper for the flow often called "fully-developed turbulent flow." The term "fluctuation" will be used in the sense of any variation with time; the term "turbulence" in the sense of irregular fluctuations of frequency greater than some selected cut-off frequency; the term "pulsation" in the sense of fluctuations of frequency lower than the cut-off frequency of the turbulence.

THE HOT WIRE ANEMOMETER

The study of turbulence in wind tunnels in a direct manner has been made possible by the hot wire anemometer. So far as I know, the first use of this instrument to measure fluctuations was that of Huguenard, Magnan, and Planiol[13] for the study of gusts in natural winds in 1923. These investigators gave a brief theoretical treatment of the problem of the lag of the instrument and a method of computing corrections for lag. In 1926, Burgers[14] described the use of wires about 0.015 mm. in diameter for measurements in wind tun-

nels. We began to study wind-tunnel turbulence by this means in 1926 using wires about 0.075 mm. in diameter and were ready to abandon the method because of the large lag when we learned of Burgers' success and were thus stimulated to further experiments.

The hot wire anemometer, as its name implies, is a wire of small diameter which may be heated by passing an electric current through it. Fig. 2 shows an enlarged view of a wire about 0.008 mm. in diameter, 1 mm. long. The wire is prepared by soldering Wollaston wire to the sewing needles which form the tips of the mounting and etching away the silver coating for a short length in the center. When the wire is hot, speed fluctuations cause changes in the rate of cooling of the wire, hence in its temperature, and, for a wire of suitable material such as platinum, in its resistance. The resulting variations in the potential drop across the wire may then be amplified and applied either to a cathode ray oscillograph for study of the detail of the fluctuation with time or to a thermal-type milliammeter which indicates the intensity of the alternating current output. The heating and cooling of the wire are affected mainly by the component of the speed fluctuation parallel to the direction of mean flow, the other components producing only second order effects. For small fluctuations, the output current is proportional to the speed fluctuation, and the oscillograph trace gives directly a record proportional to the variation of speed with time. The meter gives the root-mean-square value of the fluctuating current and from its indication the root-mean-square fluctuation of speed can be computed, a quantity designated as the intensity of the turbulence.

The instrument in its original form could not reproduce rapid fluctuations of speed. In a rapid fluctuation when the speed is decreasing, the electric current is not able to supply sufficient energy to raise the temperature of the wire fast enough to correspond to the equilibrium temperature. When the speed is increasing, the supply of energy reduces the rate of cooling. The theoretical study of this problem shows that a sinusoidal fluctuation of frequency $p/2\pi$ has its amplitude diminished in the ratio $1/\sqrt{1 + p^2M^2}$ and suffers a phase retardation of $\tan^{-1} pM$, where M is a time constant depending on the physical properties of the wire and the mean temperature and heating current at which it is operated. For the wire shown in Fig. 2, M is about 1/500 sec. The amplitudes for fluctuations of frequencies of 100, 500, 1000, and 5000 per sec. are reduced in the ratio 0.62, 0.16, 0.08, and 0.016, respectively, and shifted in phase 51.5°, 80.9°, 85.5°, and 89.1°, respectively. For a wire 0.017 mm. in diameter, the amplitude ratio at 100 cycles per sec. is 0.094 and the phase shift 89°.

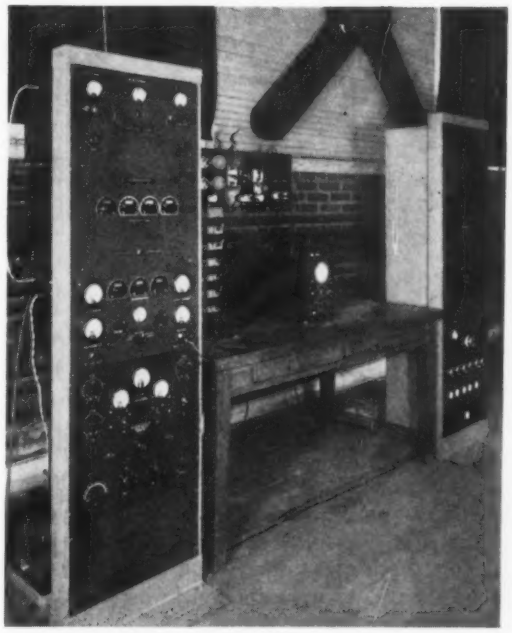


FIG. 3. Electrical equipment used with hot wire anemometer for turbulence measurements.
Power supply at right. Amplifier, compensation circuit, low frequency oscillator, switches, and meters at left.

The form of the relationship suggested that it might be possible to restore the amplitude and compensate for the lag by a suitable electrical network. The method adopted was to insert in the amplifier circuit a voltage divider consisting of an inductance and adjustable resistance in series with a large fixed resistance. The amplifier then amplifies the high frequencies more than the low and, if the ratio of inductance to adjustable resistance is made equal to the time constant of the wire, exactly compensates for the lag of the wire up to frequencies at which the unavoidable distributed capacity of the inductance begins to short circuit the voltage divider. The upper frequency limit in our present equipment is about 5000 cycles per sec. Both the theory of the lag and the theory of the compensating circuits have been experimentally verified not only in our own laboratory, but in other laboratories as well.

The amplifier and associated electrical equipment shown in Fig. 3 quite dwarfs the hot wire anemometer itself.

MEASUREMENT OF INTENSITY OF TURBULENCE BY THERMAL DIFFUSION

Another method of measuring the intensity of wind tunnel turbulence based on the diffusion of heat from a heated wire was developed by my colleague, G. B. Schubauer. It has been found by experiment that the width of the heated wake increases as the turbulence increases. The apparatus consists merely of a heated wire about 0.002 in. in diameter with provision for

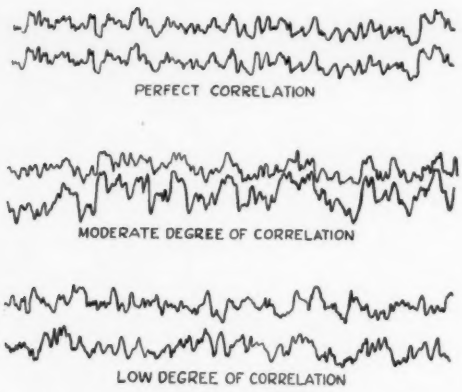


FIG. 4. Oscillograms illustrating physical meaning of correlation.

traversing a thermocouple junction across the wake. The thermocouple is connected to a sensitive galvanometer. The complete theory of this method given by Taylor shows that the angle subtended at the heated wire by the two points in the wake where the temperature rise is half that at the center of the wake, when corrected for the true thermal conductivity, is a measure of the root-mean-square fluctuation of the component of the speed at right angles to the direction of mean flow. The agreement of measurements by this method with those by the usual hot wire method demonstrates that the turbulence is in all probability isotropic.

SCALE OF WIND-TUNNEL TURBULENCE

Our first studies indicated a fairly definite relationship between the drag of spheres and the intensity of the turbulence as measured by the compensated hot wire anemometer. As more data were accumulated under a wider range of conditions, the definiteness of this relationship became more and more unsatisfactory. Millikan and Klein noted that the critical Reynolds Number of a sphere, defined as the Reynolds Number at which the drag coefficient is 0.3, depended on the diameter of the sphere. We were thus led to the idea that the scale of the turbulent pattern is also of importance as had been predicted earlier by Bacon and Reid.[15]

A study of this subject was begun in 1933. Measurements of the critical Reynolds Number of spheres were made in a stream rendered turbulent by screens of various mesh. The several screens used were approximately geometrically similar. It was supposed that the scale would be proportional to the mesh of the screen. While the experiments were in progress we learned of G. I. Taylor's definition of scale[16] in terms of the correlation between velocity fluctuations at points at varying distances apart transverse to the stream, and thereafter made direct measurements of the scale in accordance with Taylor's definition.

The physical significance of the correlation between fluctuations at neighboring points can perhaps best be understood by the aid of Fig. 4. Each of the six records represents an actual record of the variation of speed with time in a turbulent air flow. Perfect correlation is indicated by two identical records, in this case copied from the same original negative. The records showing a moderate degree of correlation were obtained by Burgers with two instruments at points 1 cm. apart. The records showing low correlation were made at the same point at different times, and the correlation is practically zero.

Fortunately, it is not necessary to make laborious computations from photographic records to give a quantitative statement about the degree of correlation. The mathematical definition of the correlation coefficient R is as follows:

$$R = \overline{u_1 u_2} / \sqrt{\overline{u_1^2}} \sqrt{\overline{u_2^2}}$$

where u_1 and u_2 are velocity fluctuations at the two points and the bars indicate average values. In wind-tunnel turbulence the root-mean-square fluctuation is substantially constant across the section and the denominator may be replaced by $\overline{u^2}$. For this case

$$R = \overline{u_1 u_2} / \overline{u^2}$$

If two hot wires at the points 1 and 2 are connected so that the fluctuations of voltage corresponding to increasing speeds oppose each other and the resultant mean-square value measured by a compensated amplifier, the quantity $\overline{(u_1 - u_2)^2}$ may be computed from this value and the calibration data. If connected so that the voltages add, the quantity $\overline{(u_1 + u_2)^2}$ may be computed. It is readily seen that, for the case in which $\overline{u_1^2} = \overline{u_2^2}$, the correlation R is equal to the difference between the two readings divided by the sum of the two readings.

By making observations for varying separation of the wires, there is obtained a curve like those shown in Fig. 5 which is reproduced from N.A.C.A. Technical Report 581. Following Taylor's recommendation, the scale of the turbulence is defined as half the area under this curve, or in mathematical terms $\int_0^\infty R\, dy$.

Extensive studies were made of the intensity and scale of the turbulence set up by wire screens at various distances from the working station. These measurements give information about the decay of turbulence and change in scale, which has an interest from the point of view of the theory of turbulence and a practical bearing on the design of wind tunnels to secure low turbulence. A discussion of these questions is, however, not germane to the present lecture.

SPHERE AS A TURBULENCE METER

The discovery of turbulence effects began with spheres and spheres have been frequently used as "turbulence meters." The required equipment is

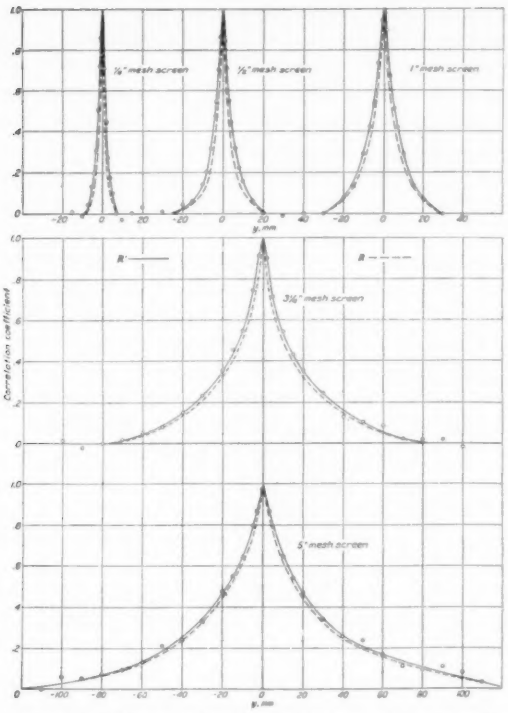


FIG. 5. Curves showing variation of correlation coefficient with the cross-stream separation of the hot wires.

R' observed curves, R curves resulting when wire-length correction is applied. Observations taken 40 mesh lengths from screens. Wind speed 40 ft./sec. (From N.A.C.A. Technical Report 581.)

much simpler than the hot wire anemometer and is for the most part readily available in every aerodynamic laboratory. To make the sphere results quantitatively definite, we suggested the definition of critical Reynolds Number of the sphere as the value of the Reynolds Number at which the drag coefficient is 0.3, not knowing that Prandtl had previously suggested the value 0.36 in a somewhat inaccessible publication. Our proposal has been rather generally adopted. More recently S. Hoerner[17] of the Deutsche Versuchsanstalt für Luftfahrt and our own group at the National Bureau of Standards independently developed a "pressure-sphere" which is more convenient in practice. In this device the pressure difference between an impact opening at the upstream stagnation point and an opening in the downstream zone of approximately constant pressure is measured. The Reynolds Number for which this pressure is equal to 1.22 times the velocity pressure is defined as the critical Reynolds Number.

Having means available for varying the intensity and scale of the turbulence independently and for measuring these quantities by means of the hot wire anemometer, we have studied their effect on the critical Reynolds Number of spheres. While the measurements were in progress G. I. Taylor[18] suggested that the critical Reynolds Number should be a function of

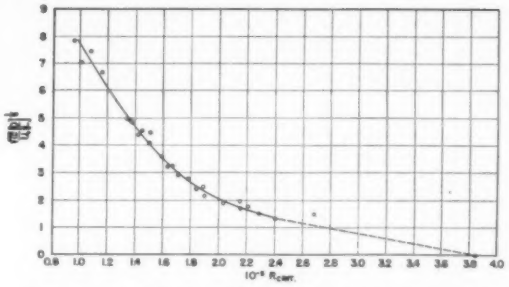


FIG. 6. Critical Reynolds Number of spheres as a function of the Taylor turbulence parameter, $(\sqrt{\overline{u^2}}/U_0)(D/L)^{1/5}$.

D is the diameter of the sphere, L the scale of the turbulence, U_0 the speed of the free stream, $\sqrt{\overline{u^2}}$ the root-mean-square speed fluctuation. The critical Reynolds Number is the value of U_0D/ν at which the pressure coefficient of a pressure sphere is 1.22, ν being the kinematic viscosity.

the product of intensity by the fifth root of the ratio of the diameter of the sphere to the scale of the turbulence. Our measurements confirmed this relation surprisingly well. The calibration curve of the pressure sphere as a turbulence meter is shown in Fig. 6. The point for zero intensity of turbulence is based on the experiments at Langley Field described by Platt.[19] These experiments included tests in flight and towing tests through still air in the N.A.C.A. tank building. Under stable conditions the air was known to be free of all fluctuations of the type generally considered as wind-tunnel turbulence, and this was taken as the zero turbulence condition. The agreement between the critical Reynolds Numbers of the spheres towed both in the tank and in flight tends to confirm other indications later to be mentioned that the effective turbulence in free air is substantially zero.

General Features of Boundary Layer Flow

Most of the effects of turbulence in aerodynamic measurements are believed to be due to one basic effect, namely, the effect of turbulence on boundary layer flow. The flow within the boundary layer may be either of the laminar or of the eddying type or of a transition type in which the flow is changing from laminar to eddying. The principal effect of turbulence is to modify the conditions under which transition occurs.

From the theoretical point of view the laminar flow is a steady flow in which the only mechanism for transfer of momentum is the thermal motion of the molecules whose effect on the process can be expressed by the viscosity. From the experimental point of view, the laminar flow is not steady. Fluctuations are observed to be present, including turbulence swept into the boundary layer from the free stream, but the presence of the fluctuations does not, for a time at least, produce any measurable departure from the distribution of mean speed computed on the assumption of a steady flow. The principal fluctuations are believed to have the character of those which would be produced

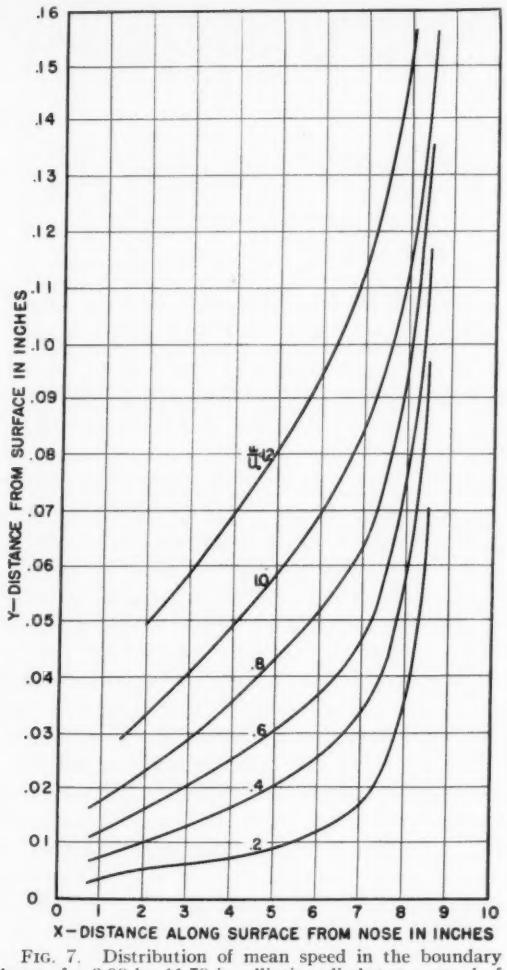


FIG. 7. Distribution of mean speed in the boundary layer of a 3.98 by 11.78 in. elliptic cylinder at a speed of 11.5 ft./sec.

x is the distance measured along the surface from the stagnation point at the nose, y the perpendicular distance from the surface, U_0 the speed of the free stream. The contours are contours of equal mean speed, the number on each contour being the corresponding value of u/U_0 where u is the mean speed at the point whose coordinates are x and y.

These measurements were made in a stream in which the intensity of the turbulence was 0.85 percent of the mean speed and the scale was 0.26 in.

by changes in thickness of the boundary layer as a whole. The term "laminar flow" will be used to denote the type of flow in which the distribution of mean speed is in reasonable agreement with the theoretical distribution, irrespective of the presence or absence of fluctuations.

The discussion immediately following relates to studies of the spatial distribution of mean speed, whereas most of the preceding discussion dealt with the fluctuations of the speed with respect to the mean speed at a single point or at neighboring points. The measurements referred to later were made with hot wire anemometers used in the ordinary manner for measurement of mean speed.

The concept of the boundary layer and the theoretical equations of laminar flow within a boundary layer were first announced by Prandtl[20] in 1904. Not until twenty years later was it possible to make measurements of the distribution of mean speed within a boundary layer. Even today the detailed studies of boundary layers described in the literature are few in number. The experimental technique is difficult. In the free flight studies of Jones[1] and of Stüper[21] the thickness of the layer did not exceed $^1/_4$ in. over the forward part of the wing in which the interesting phenomenon of transition occurred. In model experiments the thickness is usually less than $^1/_{16}$ in. in the region of most interest. Notwithstanding the difficulty of measurement, it is essential to obtain the distribution of mean speed in typical boundary layers in sufficient detail to guide the interpretation of measurements made by simpler and more rapid methods. Such measurements have been sponsored by the National Advisory Committee for Aeronautics in its cooperative program at the National Bureau of Standards.

The results of such measurements are usually plotted in terms of the ratio of the mean speed u at any point within the boundary layer to the aircraft or wind-tunnel speed U_0. This ratio for cases of two-dimensional flow as, for example, around a wing section not too close to the tips, is a function of two coordinates, one the distance x from the leading edge* measured along the surface to the foot of the perpendicular to the surface from the point at which the speed is u, the other the perpendicular distance y from the point to the surface. It is common practice to plot curves of u/U_0 vs. y for various values of x, and from the shape of these curves to judge whether the flow in the boundary layer is laminar or eddying or of the transition type in which the flow is changing from laminar to eddying. We have found it helpful to adopt a different method of presentation which makes it possible after a little practice to grasp the general features of the flow at a glance.

Fig. 7 illustrates this method of plotting for the results given by Schubauer in N.A.C.A. Technical Report 527 for the flow in a separating laminar boundary layer, occurring on the surface of an elliptic cylinder at low Reynolds Numbers. This figure is in the nature of a contour map of the three-dimensional figure which would be obtained by plotting u/U_0 vertically upward from the plane of the paper at points with coordinates x and y corresponding to the x and y distances previously defined, the y coordinate being magnified 100 times relative to the x coordinate. The speed at any point is found by entering the diagram at coordinates equal to the x and y distances in the boundary layer and interpolating between the contours of equal speed.

* Strictly speaking, here and elsewhere, this distance should be measured from the "stagnation point," the point of division on the surface between the streams passing above and below the wing.

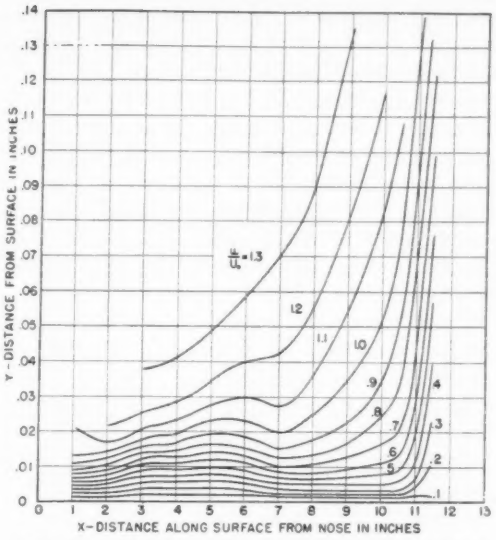


FIG. 8. Distribution of mean speed in the boundary layer of a 3.98 by 11.78 in. elliptic cylinder, speed 60 ft./sec., intensity of turbulence about 4 percent, and scale about 0.27 inch. (For notation, see legend of Fig. 7.)

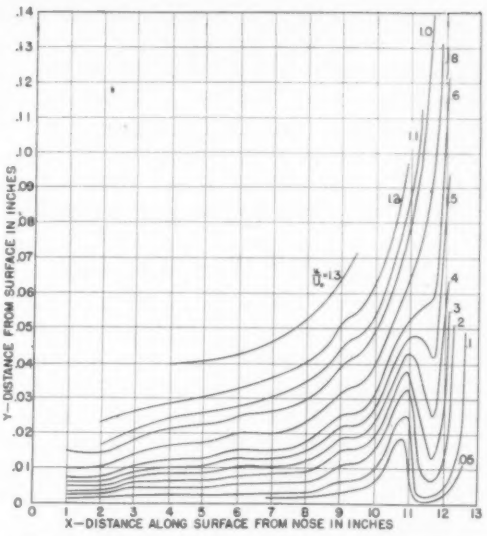


FIG. 9. Distribution of mean speed in the boundary layer of a 3.98 by 11.78 in. elliptic cylinder, speed 70 ft./sec., intensity of turbulence 0.85 percent, and scale 0.26 in. (For notation, see legend of Fig. 7.)

The conventional plots of u/U_0 vs. y can be reconstructed by reading off at a given x the y values intersected by the contours of the even values of u/U_0, and with a little practice the general shape of these cross plots can be visualized without actually constructing them. Similarly for cross plots of u/U_0 vs. x at constant values of y, a type of plot which Jones found useful in identifying transition.

In Fig. 7 the more or less regularly spaced contours up to $u/U_0 = 0.6$ or a little more, rising slowly toward the right, and the regularly increasing separation of the contours at greater values of u/U_0 are characteristic of laminar flow, a type of flow accurately described by Prandtl's theoretical equations. Cross plots of u/U_0 against y at constant x would show the well known characteristic laminar distribution, and cross plots of u/U_0 against x at constant y would show a slowly decreasing speed as the flow is slowed down by friction.

The abrupt change in slope of the contour lines to many times its previous value at x equal to about 8 in. is characteristic of the separation of the flow from the surface and the distribution at greater values of x cannot conveniently be shown in a diagram of the same scale.

Fig. 8 shows another example of this method of presenting the speed distribution in boundary layers. This diagram applies to the boundary layer of the same elliptic cylinder at a higher Reynolds Number and in a turbulent air stream. For values of x less than about 5 in. there is observed the form of contours typical of laminar flow and at x equal to 11 in. that typical of separation. Between 5 and 8 in., there is a different phenomenon. The contours instead of rising toward the right fall toward the axis of x. A cross plot of u/U_0 vs. x at y equal to 0.01 in. would show the speed ratio reaching a minimum of 0.5 at $x = 5$ in., then rising to 0.7 at $x = 7$ in., then decreasing again. This is the behavior characteristic of transition, since only the onset of eddying motion can accelerate the flow. It will be noted that the contours for the highest values of u/U_0 do not exhibit this behavior, but their slope increases greatly following transition.

Still another example of the contour diagram is shown in Fig. 9, which was presented last year in the discussion of Professor Jones' lecture. The boundary layer is that of the same elliptic cylinder in an air stream of smaller turbulence. Here the flow is typically laminar up to $x = 10$ in., at which point the contours are of the type characteristic of separation. From $x = 10.8$ to $x = 11.5$, the inner contours fall rapidly toward the x axis with increasing x and hence indicate transition. At $x = 12$, separation again occurs. This contour diagram is interpreted as showing separation of a laminar layer, followed by transition, reattachment to the surface, and a subsequent separation.

The general features of boundary layer flow may easily be recognized from such diagrams according to the following key:

Contours rising slowly with increasing distance from the leading edge, regularly spaced for u/U_0 from 0 to 0.6, regularly increasing spacing for higher values of u/U_0	Laminar flow as described by Prandtl's equations.
Contours with slope abruptly increasing to many times the previous slope for all values of u/U_0	Separation.
Contours for u/U_0 less than 0.6 falling with increasing distance from the leading edge, those for large values of u/U_0 rising with increased slope	Transition.

In none of the diagrams of Figs. 7, 8, and 9 is the flow of the eddying type, although there is an approach to it for x between 8 and 11 in. in Fig. 8. The contours for values of u/U_0 less than about 0.6 are closely spaced, while those near the outer part of the layer are separated more widely. In other words, the speed ratio rises to 0.6 in a comparatively small fraction of the thickness of the boundary layer in eddying flow.

Laminar Boundary Layer

The theory of the laminar boundary layer has been sufficiently checked experimentally to verify the adequacy of Prandtl's equations for computing the speed distribution, so long as the layer remains laminar. The assumption of the theory that the flow is a steady flow has been found not always true, for speed fluctuations of considerable magnitude have been found in laminar layers in wind tunnels. Nevertheless the presence of these fluctuations does not cause any immediate discrepancy between theory and experiment. In free flight, Stephens[22] found no appreciable fluctuation at frequencies greater than about 20 per sec., the lower cut-off frequency of his hot wire apparatus.

The practical importance of maintaining a laminar boundary layer over as much of the surface of an aircraft as possible is associated with the low drag when the layer is laminar. Two phenomena may intervene to modify the laminar layer, separation or transition. Both phenomena are affected by turbulence, the first indirectly, the second directly.

Separation

The development of the boundary layer and the speed distribution within it are greatly modified by the pressure distribution over the surface on which the boundary layer forms. When, for example, the pressure falls in the direction of flow as it does over the forward part of an airfoil the boundary layer is much thinner (except very near the leading edge) than it would be with a constant pressure and the thickness increases more slowly with increasing distance from the stagnation point, or may even begin to decrease if the gradient increases so that the pressure falls still more rapidly.

When on the other hand the pressure increases in the direction of flow, the boundary layer thickens rapidly. The fluid near the wall is acted on by the frictional drag of the outer faster moving layers tending to carry it along with the flow, by the frictional drag of the layers next to the wall tending to retard its motion, and by the pressure gradient which also retards its motion. As the layer thickens the frictional forces become small but the force due to the pressure gradient is unchanged. The retarding effect therefore predominates and finally causes a reversal of the flow. The reversal of flow, on account of the consequent accumulation of fluid, separates the flow from the surface. The beginning of separation is marked by the reversal of flow, which can be detected by such devices as applying a mixture of kerosene and lampblack to the surface and observing the pattern established by the flow near the surface or by applying a solution of litmus to the surface and releasing a tiny jet of ammonia gas near the surface. The hot wire anemometer used in obtaining the speed distributions of Figs. 7, 8, and 9 is insensitive to direction and hence gives no sharp indication of flow reversal.

The effects of separation are well known. The drag is greatly increased, a violent eddying wake is formed, the lift is reduced. Stalling of airfoils is an evidence of separation of the flow. The high drag of poorly faired objects is due to flow separation.

In laminar flow the driving action of the friction of the outer layers is due solely to the thermal motion of the molecules evidenced by the viscosity. In eddying flow there is a more thorough mixing of the fluid particles, and the driving action is greater. Hence the fluid is enabled to flow farther against adverse pressure gradients when the boundary layer flow is eddying. Thus while a laminar boundary layer is advantageous from the standpoint of securing low drag, there is a danger of earlier separation of the flow, which produces a very high drag.

Transition

The other phenomenon which intervenes to break down the laminar boundary layer is that of transition. Much research has been conducted to determine exactly what takes place when transition occurs. We know definitely that what takes place is *not*, as previously supposed, the change from a smooth steady flow to an unsteady flow with speed fluctuations, at least so far as wind-tunnel experiments are concerned, for the laminar flow contains large speed fluctuations.

The chief experimental facts with regard to the changes in the mean speed distribution have already been stated. The speed at a fixed small distance from the surface, which in the laminar part of the layer decreases with increasing distance from the stagnation point, falls to a minimum, rises to a maximum with further increase in distance, and then decreases again. The region of rising speed is termed the transition region and the position of the minimum speed the transition point.

Basic Effect of Turbulence

The principal and basic effect of turbulence in aerodynamic measurements is the effect of turbulence on transition. In quite general terms, where an effect is present, an increase in the intensity or decrease in the scale of the turbulence causes an earlier transition, that is, one closer to the leading edge, or for a fixed location at lower Reynolds Number.

Thus, for spheres at low values of the Reynolds Number, the flow in the boundary layer is laminar and sepa-

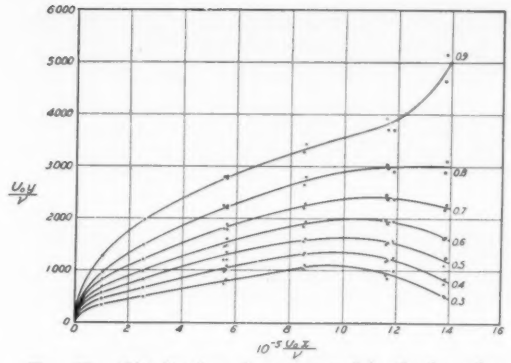


FIG. 10. Distribution of mean speed in the boundary layer of a flat plate, speed 105 ft./sec., intensity of turbulence 0.5 percent, scale not measured.

For notation, see legend of Fig. 7. The coordinates have been made non-dimensional by multiplying x and y by the speed of the free stream U_0 and dividing by the kinematic viscosity ν.

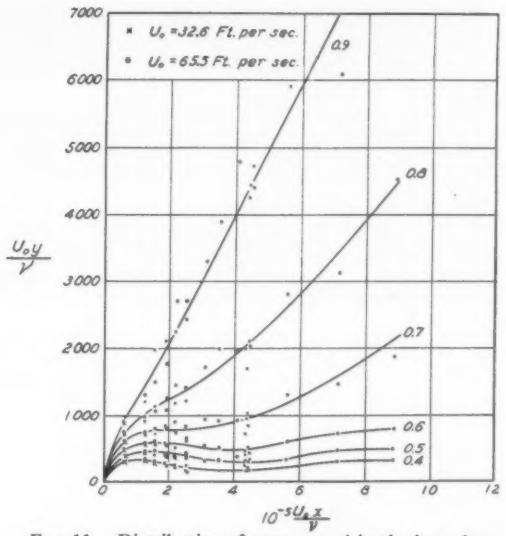


FIG. 11. Distribution of mean speed in the boundary layer of a flat plate, speed 32.6 and 65.5 ft./sec., intensity of turbulence 3.0 percent, scale not measured.

For notation, see legend of Fig. 7. The coordinates have been made non-dimensional by multiplying x and y by the speed of the free stream U_0 and dividing by the kinematic viscosity ν.

ration occurs at a definite location not dependent on the Reynolds Number. As the Reynolds Number is increased, transition finally takes place ahead of the laminar separation point, separation is delayed, the wake is smaller, and the drag is decreased. The skin friction in this case is negligible. If the turbulence is increased, transition occurs at a lower Reynolds Number and the critical Reynolds Number of the sphere is reduced.

On airfoils, the explanation is similar except that earlier transition and delayed separation cause higher lift.

On airship, nacelle, or fuselage models of streamline form or airfoils at small angle of attack, earlier transition means a greater part of the surface exposed to the higher drag associated with eddying flow and hence greater total drag.

The study of this basic effect of turbulence is best begun by eliminating all other factors, in particular, separation and other phenomena associated with the presence of pressure gradients. For this reason our first systematic study was made on the flow near a thin flat plate with a sharp symmetrical leading edge, the plate being set parallel to the air flow and the pressure gradient adjusted to be approximately zero. Unfortunately at the time those studies were made, the importance of the scale of the turbulence was unknown and methods of measuring the scale had not been developed. Therefore only the intensity of the turbulence was measured.

The fundamental effect of turbulence is shown by a comparison of Figs. 10 and 11, which are contour diagrams of the same type as the preceding ones except that x and y have been made non-dimensional and the magnification of y relative to x is 500 instead of 100. Fig. 10 shows the distribution for a turbulence of intensity 0.5 percent of the mean speed, the lowest then obtainable and Fig. 11 shows the corresponding distribution for a turbulence of intensity 3.0 percent of the mean speed. The transition occurs at a Reynolds Number of 1,100,000 in the first case; 100,000 in the second, the Reynolds Number being based on the speed in the free stream and the distance of the transition point from the leading edge.

Professor Jones reported values as high as 3,000,000 in a wind tunnel of low turbulence at Cambridge. We have just completed the construction of a wind tunnel for which the critical Reynolds Number of a 5 in. sphere is about 360,000. The intensity has not been directly measured as yet but from Fig. 6 it may be inferred that it is probably of the same order as that in the Cambridge tunnel. Apparatus is being constructed for further work on the basic effect of turbulence on a plate but no experimental results have been obtained at the time of preparing this lecture.

In the earlier experiments, measurements were made of fluctuations. The laminar layer was found to exhibit large fluctuations of magnitude about three times those in the turbulence of the free stream. As the transition region was approached, the magnitude increased rapidly to a maximum near the middle of the transition region. In the eddying flow following transition, the fluctuations were less than in the transition region.

Fig. 12A shows a record of the time fluctuations of the speed in the transition region of the plate. It will be observed that there is an alternation between a very slow fluctuation characteristic in these measurements of the laminar layer and a fast fluctuation characteristic of the eddying layer. Transition is thus a sudden

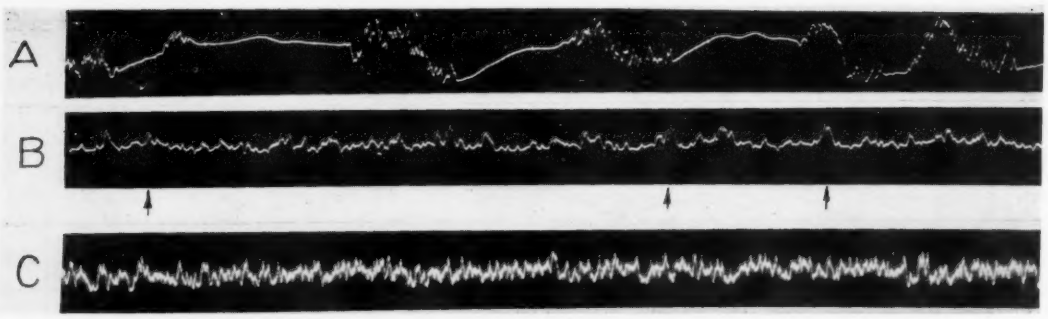


FIG. 12. Speed fluctuations in the transition region indicated by the distribution of mean speed.
A. For the flat plate, showing intermittent transition from "slow" to "fast" fluctuations.
B. For the elliptic cylinder in a stream of low turbulence, showing a trace of the behavior illustrated in A.
C. For the elliptic cylinder in a stream of high turbulence, showing no change in character of the fluctuations.

phenomemon in this case, but the transition point moves back and forth along the plate.

In the more recent experiments on the elliptic cylinder it has been shown that this behavior of the fluctuations is not of general occurrence. Thus Fig. 12B shows the fluctuations at $x = 10.66$ in. for the boundary layer of Fig. 9. There is a small indication of the phenomenon observed on the plate at the places indicated by the arrows but the contrast is not nearly so marked. In this case, however, we are dealing with the transition of a separated laminar layer.

Fig. 12C shows the fluctuations at $x = 5.4$ for the boundary layer of Fig. 8 in the stream of large turbulence. Here there is no sign of any sudden change and in fact in these experiments no change in the general character of the fluctuations could be observed from that of the fluctuations in the free stream in laminar layer, transition region, or eddying layer. The *magnitude* of the fluctuations, however, did show a maximum in the transition region as in the case of the plate.

Thus the distinction between the laminar and eddying flow cannot be based on the absence or presence of fluctuations or with certainty on differences in their frequency. The important difference between the fluctuations in laminar and eddying flow must lie in the correlation between the component of the fluctuations in the direction of the mean flow and the component at right angles to the surface along which the boundary layer is formed. A technique of measuring this correlation in a moderately thick boundary layer has recently been developed by my colleague, H. K. Skramstad. This technique has not yet been applied to the present problem, and much further development will be required to make such measurements in the very thin laminar layer.

In the absence of direct proof we may speculate that the laminar fluctuations in a boundary layer in a stream of small turbulence represent pulsations in thickness of the layer which increase in amplitude until separation occurs during part of the cycle of pulsation. Discussion along this line is given in N.A.C.A. Technical Report 562. In a boundary layer in a very turbulent stream, the random fluctuations of the isotropic turbulence of the stream are swept into the boundary layer. The velocity gradient begins to produce a correlation between the components of the fluctuations in the direction of and at right angles to the direction of mean flow, and the correlation gradually produced reacts on the velocity distribution to give a gradual transition.

THE FACTORS AFFECTING TRANSITION

The location of the transition point is known to be affected, at least in certain instances, by seven variables: the Reynolds Number, the intensity of turbulence, the scale of turbulence, the pressure gradient, location of the laminar separation point, the curvature of the surface, and the roughness of the surface. A coordinated program of research on the influence of these seven variables has been sponsored and financed by the National Advisory Committee for Aeronautics at various university laboratories, at the National Bureau of Standards, and in its own laboratories.

The California Institute of Technology is studying the influence of curvature and roughness. The results so far obtained are on a plate bent to a radius of 20 in. With a hot wire anemometer in a fixed position the Reynolds Number is varied by varying the speed until transition occurs at the measuring station. This process is repeated for several positions. The resulting data then give the location of the transition point as a function of the Reynolds Number of the general flow. The transition point moves forward as the Reynolds Number increases, both on the convex and on the concave sides. The Reynolds Number of the general flow required to give transition at a given distance from the leading edge is two or more times as great on the convex side as on the concave side. In the progress report[23] these data are analyzed on the assumption that transition depends only on certain local characteristics of the boundary layer at the transition point. If this assumption were true, the data could be used to predict the transition on plates with other radii of curvature including a flat plate. The predicted value for a flat plate is not in agreement with results of other

laboratories for air streams of corresponding turbulence, and this may be taken as an indication that transition cannot be solely a function of the selected *local* boundary layer characteristics.

While no systematic study of the effect of roughness on transition on plates has yet been reported, it is well known that roughness has a large effect. In the remaining discussion it will be assumed that the bodies under study are sufficiently smooth so that any slight roughness present has no appreciable effect.

The Massachusetts Institute of Technology is studying the influence of pressure gradient. The results have not yet been reported in detail, but here again a substantial effect is known to exist. In our own experiments on a plate, transition was delayed from an x-Reynolds Number of 1,100,000 to 1,800,000 by a fall in pressure amounting to 5 percent of the velocity pressure between leading edge and transition point.

Our recent experiments on the elliptic cylinder as well as experiments by von Doenhoff[24] at Langley Field have shown that transition will occur earlier in a separated laminar layer than in one attached to a surface. At a sufficiently high value of the Reynolds Number, separation is followed by immediate transition. The eddying layer may then reattach itself to the surface. The application of this concept to scale effect on the maximum lift of airfoils reported by von Doenhoff[24] leads to a plausible explanation of the experimental data available.

The study of the effect of turbulence on transition is the responsibility of the National Bureau of Standards in the general program. We have recently studied in some detail the effect of intensity and scale of turbulence on transition in the boundary layer of the elliptic cylinder to which frequent reference has been made. The method of locating transition was essentially the same in principle as that used by Jones except that a hot wire 0.00063 in. in diameter located about 0.008 in. from the surface was used instead of a surface pitot tube. A summary of the results at a constant Reynolds Number of 118,000, based on free stream speed and minor axis of the elliptic cylinder, is shown in Fig. 13. The distance of the transition point from the leading edge is plotted as a function of the Taylor turbulence parameter, product of intensity of turbulence by the fifth root of the ratio of the minor axis of the elliptical cross section (reference length) to the scale of the turbulence. The use of this parameter coordinates the results for varying intensity and scale of turbulence as it did for spheres.

This curve has the curious feature that when the Taylor parameter is reduced below 0.03, there is no further rearward movement of the transition point beyond 6.1 in. from the nose. It is as if some other factor had taken control and forced transition at this point. My colleague, G. B. Schubauer, called attention to the fact that the 6.1 in. position is roughly the

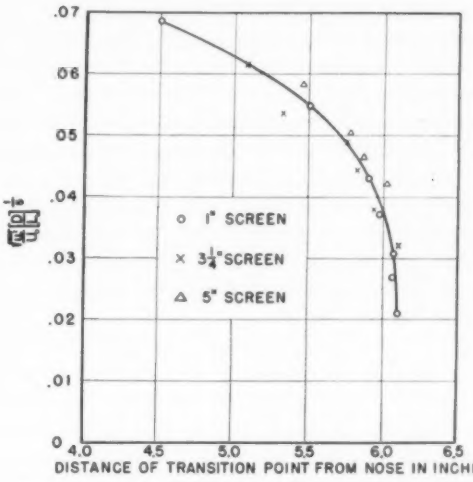


FIG. 13. Location of the transition point on an elliptic cylinder as a function of the Taylor turbulence parameter at a constant Reynolds Number.

The Reynolds Number based on the length of the minor axis of the elliptic cross section was 118,000.

D is the length of the minor axis, L the scale of the turbulence, U_0 the speed of the free stream, $\sqrt{\overline{u^2}}$ the root-mean-square speed fluctuation.

place where the pressure ceases to decrease and begins to increase, and suggests that the retarding pressure gradient causes immediate transition.

It is rather generally believed that the effect of turbulence is to superpose fluctuating pressure gradients on the mean flow, and that as the layer thickens, separation occurs in the retarding cycle of the fluctuating gradient, leading to the establishment of eddying flow. Taylor's parameter is in fact a measure of the root-mean-square pressure gradient produced by the turbulence.

I agree with Professor Jones that our original hope, that transition would depend solely on the local conditions in the boundary layer at the transition point as described by boundary layer thickness, speed of the air just outside the boundary layer, intensity and scale of turbulence just outside the boundary layer, pressure gradient, and curvature, is no longer tenable. If then we turn to the methods of dimensional analysis as applied to a smooth body of specified shape and orientation, we find that the ratio of the distance of the transition point from the leading edge to the reference length is a function of the Reynolds Number and of the turbulence, the experimental results suggesting that scale and intensity of turbulence need to be considered only in the combination of the Taylor parameter. Pressure distribution, separation, and curvature no longer appear as independent variables. The whole story of transition could then be expressed for this one body at one orientation by a family of curves like Fig. 13. Fig. 13 applies to a single Reynolds Number. At higher Reynolds Numbers the upper part of the curve is displaced somewhat to the left, and at lower Reynolds Numbers the curve approaches a vertical

straight line at $x = 6.1$ in. The detailed study with the surface hot wire indicates in fact that even for the boundary layer shown in Fig. 9 transition begins at $x = 6.1$ in. but for some reason does not fully develop, perhaps because of the stabilizing effect of the decreasing radius of curvature of the surface. The first separation which has hitherto been termed a laminar separation is that of a nearly laminar layer. Transition is completed in the separated layer. As the Reynolds Number is reduced, the evidence of transition at 6.1 in. gradually disappears, and transition begins in the separated laminar layer.

This method of analysis in terms of families of curves relating the transition point to Reynolds Number and the Taylor turbulence parameter is not very satisfactory because it affords no basis for inferring the location of the transition on other bodies or even on the same body at a different orientation. In the study of airfoils, for example, each angle of attack corresponds in effect to a new body and a new family of curves. It is well known that the effect of Reynolds Number is a function of angle of attack, and the same is true for the effect of turbulence.

Relation between the Effects of Turbulence and of Reynolds Number

A few years ago there was considerable discussion of the relation between the effects of turbulence and of Reynolds Number. Both effects arise principally from an influence on transition. Either an increase in Reynolds Number or an increase in turbulence will cause the transition to occur closer to the leading edge, when any effect is present, and in this rough qualitative sense the effects of increased turbulence and increased Reynolds Number are equivalent. Empirically an approximate relationship can be found if one is dealing with a definite type of flow, say a flow involving separation. Maximum lift coefficients of airfoils at various Reynolds Numbers measured in wind tunnels of different turbulence have been brought into reasonable agreement on the assumption that the effect of turbulence is equivalent to a shift in the Reynolds Number scale, the shifted Reynolds Number being designated the effective Reynolds Number. The use of effective Reynolds Number does not, however, bring the measurements of profile drag to a single curve, and further adjustments based on a more complete understanding of the nature of turbulence effects must be made.

It has become quite clear now that this simplification cannot be justified from any theoretical point of view. The use of large turbulence in a wind tunnel to simulate flow at large Reynolds Number is then to be considered only when the interest is in qualitative rather than quantitative results. The modern trend is toward the design of wind tunnels permitting tests at high Reynolds Number in air streams of low turbulence.

Atmospheric Turbulence

This modern trend toward wind tunnels of low turbulence has developed not merely because it is much easier to add turbulence than to remove it but also because we believe that the turbulence in the free atmosphere is substantially zero. In view of the frequent presence of natural winds continually varying in direction and magnitude, this situation is somewhat paradoxical and requires explanation.

The paradox arises from the ambiguity of the word, turbulence, and the unavoidable arbitrary character of its definition. Before a definite meaning can be ascribed to turbulence, the mean speed must be defined and the definition of mean speed presupposes the selection of a definite time interval over which the mean is to be taken. In the case of the natural wind, or an aircraft flying in a natural wind, the value of the mean speed depends very much on whether the time interval is one hour, one minute, or one second. Generally speaking, the larger the time interval, the greater will be the intensity and scale of the "turbulence." When a small time interval is used, the mean value varies slowly, but this variation is considered as merely a variation of mean speed—not as turbulence. For no value of the interval, is the mean speed likely to be constant from interval to interval.

Studies of gusts in natural winds by the usual anemometers show a large scale turbulence of considerable intensity when referred to mean speed over a five minute interval. The scale is of the order of 100 ft. or more and the intensity of the order of 5 m.p.h. or more. The Taylor turbulence parameter for a 6 in. sphere flown at air speeds of the order of 100 m.p.h. is then of the order of 0.017 which from Fig. 6 corresponds to a critical Reynolds Number of 220,000. When the actual experiment was tried by Millikan and Klein[10] in 1933, a value of 365,000 was obtained. Measurements by Hoerner[17] in 1935 and Platt[19] in 1936 with the pressure-sphere technique gave a value of 385,000 at a pressure coefficient of 1.22*.

Millikan and Klein[10] report efforts by Wattendorf and Kuethe to make hot wire experiments in flight in 1933 which were not completely successful but did show that the turbulence measured by the hot wire anemometer could not be greater than 0.4 percent and was probably less than 0.2 percent. Stephens last year was more successful and confirmed the belief that the turbulence measured in this way is quite low. In both series of experiments the lower cut-off frequency of the amplifier was not stated, but was probably of the order of 20 cycles per sec. Certainly the equipment did not respond to the gusts recorded by the ordinary anemometers.

* Hoerner uses a pressure coefficient of 1.00 which corresponds to a higher value, about 400,000. Fig. 6 applies to the pressure sphere with a pressure coefficient of 1.22.

It cannot be stated too emphatically that the definition of turbulence is necessarily arbitrary and the most useful definition depends on the purpose of the study. When the interest is in the effect of turbulence on the flow in the boundary layer of an airplane wing, the time interval over which the mean speed should be taken is logically that required for the airplane to travel a reasonable number of chord lengths, perhaps 10. If the chord is 8 ft. and the speed is 250 m.p.h., the airplane will travel 10 chord lengths in 0.22 sec. Fluctuations whose frequency was less than 5 per sec. would be regarded as changes in mean speed which might impart accelerations to the airplane as a whole but certainly could not influence the stability of the boundary layer. Fluctuations of greater frequency than 5 per sec. would constitute the turbulence of interest in this problem.

The averaging required could equally well be stated in terms of scale. Turbulence whose scale is much greater than the wing chord is not expected to influence boundary layer flow. Hence the turbulence in the atmosphere of interest in connection with transition is that whose scale is small compared to the wing chord. In this sense, all evidence available indicates that the turbulence of the atmosphere is very small and probably zero.

From the point of view of accelerations of the aircraft as a whole, the turbulence is decidedly not zero, but fortunately the aerologist prefers to call the turbulence which he studies "gustiness," so no confusion need arise.

The Note of Interrogation

In setting the pattern for this lecture last year, Professor Jones stated at the outset that his lecture would end on a note of interrogation. The research on transition, one year later, is still in that state in which the number of questions raised by new experiments is greater than the number of questions answered by those experiments. If transition in wind tunnels appears to be associated with the growth of fluctuations in the laminar layer induced in large measure by the turbulence of the stream, and if there is no turbulence in the atmosphere, why should transition occur at all under conditions of free flight? To this question I can assuredly give no positive and direct answer, but with your permission I will bring this lecture to a close with certain speculations which may or may not turn out to be true.

It seems to me that when we do not have the dominating influence of the turbulence of the stream, the problem reverts to one of the stability of the laminar motion under various circumstances, and in particular to the degree of instability of the laminar motion. Schlichting, for example, computed the damping or amplification of small disturbances in the laminar flow near a plate with zero pressure gradient and found what may be termed a mild amplification within the range of Reynolds Numbers of interest. Tollmien computed the amplification for velocity distributions having an inflection point, which occur in boundary layers with retarding pressure gradient and found values considerably greater than those for the flow near a plate. A separated "free" laminar layer is extremely unstable at moderate Reynolds Numbers, so much so that transition almost always occurs immediately following laminar separation. Jones refers to the favorable influence of a falling pressure gradient in "conditioning" a boundary layer to resist transition. The favorable influence of a convex curvature of the surface has already been noted. All of these influences are present in any actual surface. It seems to me quite conceivable that the relative instability of the boundary layer at various distances from the leading edge as determined by the curvature and the pressure distribution (which controls the position of the laminar separation point) may control the point of transition within narrow limits independently of the magnitude of the small disturbance whose amplification produces transition. It is hoped that more light may be thrown on this question by studies of the fluctuations in a wind tunnel of extremely low turbulence. In experiments made to date there have always been fluctuations at the leading edge and the wake is always a possible source of fluctuations. The answer to all these questions lies in further following in the footsteps of the Wright Brothers—more experiment, by scientists and engineers, in flight and in wind tunnels.

References

[1] Jones, B. Melvill, *Flight Experiments on the Boundary Layer*, Journal of the Aeronautical Sciences, Vol. 5, No. 3, page 81, January, 1938.

[2] Reynolds, Osborne, *An Experimental Investigation of the Circumstances Which Determine Whether the Motion of Water Shall be Direct or Sinuous and of the Law of Resistance in Parallel Channels*, Phil. Trans. Roy. Soc., Vol. 174, page 935, 1883.

[3] Eiffel, G., *La resistance de l'air et l'aviation*, page 76; Dunod et Pinat, Paris, 1911.

[4] Föppl, O., *Ergebnisse der aerodynamischen Versuchsanstalt von Eiffel, verglichen mit den Göttinger Resultaten*, Zeitschrift für Flugtechnik und Motorluftschiffahrt, Vol. 3, No. 9, page 118, 1912.

[5] Eiffel, G., *Sur la résistance des sphères dans l'air en mouvement*, Comptes Rendus, Vol. 115, page 1597, 1912.

[6] Wieselsberger, C., *Der Luftwiderstand von Kugeln*, Zeitschrift für Flugtechnik und Motorluftschiffahrt, Vol. 5, No. 9, page 140. 1914.

[7] Prandtl, L., *Der Luftwiderstand von Kugeln*, Nachrichten der Königlichen Gesellschaft der Wissenschaften, Göttingen, Math. phys. Kl., page 177, 1914.

[8] Higgins, George J., *Tests of the N.P.L. Airship Models in the Variable Density Wind Tunnel*, N.A.C.A. Technical Note 264, 1927.

[9] Dryden, H. L., and Kuethe, A. M., *Effect of Turbulence in Wind Tunnel Measurements*, N.A.C.A. Technical Report 342, 1930.

[10] Millikan, C. B., and Klein, A. L., *The Effect of Turbulence. An Investigation of Maximum Lift Coefficient and Turbulence in*

Wind Tunnels and in Flight, Aircraft Engineering, Vol. 5, No. 54, page 169, August, 1933.

[11] Dryden, Hugh L., *Turbulence, Companion of Reynolds Number*, Journal of the Aeronautical Sciences, Vol. 1, No. 2, page 67, April, 1934.

[12] Kármán, Th. von, *Turbulence (Twenty-Fifth Wilbur Wright Memorial Lecture)*, Journal of the Royal Aeronautical Society, Vol. 41, No. 324, page 1109, December, 1937.

[13] Huguenard, E., Magnan, A., and Planiol, A., *Sur une méthode de mesure de la vitesse et de la direction instantanées du vent*, La Technique Aeronautique, Vol. 14, No. 25, page 798, Nov. 15, 1923; Vol. 14, No. 26, page 854, Dec. 15, 1923; Vol. 15, No. 27, page 7, Jan. 15, 1924; and Vol. 15, No. 28, page 47, Feb. 15, 1924. (Translated in N.A.C.A. Technical Memorandum 264.)

[14] Burgers, J. M., *Experiments on the Fluctuations of the Velocity in a Current of Air*, Proc. Kon. Akad. v. Wetenschappen, Amsterdam, Vol. 29, page 547, 1926.

[15] Bacon, D. L., and Reid, E. G., *The Resistance of Spheres in Wind Tunnels and in Air*, N.A.C.A. Technical Report 185, 1924.

[16] Taylor, G. I., *Statistical Theory of Turbulence, Parts I, II, III, and IV*, Proc. Roy. Soc. (London), Vol. 151, No. 873, page 421, September, 1935.

[17] Hoerner, S., *Versuche mit Kugeln betreffend Kennzahl, Turbulenz und Oberflachenbeschaffenheit*, Luftfahrtforschung, Vol. 12, No. 1, page 42, March, 1935. (Translated in N.A.C.A. Technical Memorandum 777.)

[18] Taylor, G. I., Statistical Theory of Turbulence, Part V, Proc. Roy. Soc. (London), Vol. 156, No. 888, page 307, August, 1936.

[19] Platt, R. C., *Turbulence Factors of N.A.C.A. Wind Tunnels as Determined by Sphere Tests*, N.A.C.A. Technical Report 558, 1936.

[20] Prandtl, L., *Über Flüssigkeitsbewegung bei sehr kleiner Reiburg*, Proc. 3d Intern. Math. Congress, Heidelberg, 1904. (Translated in N.A.C.A. Technical Memorandum 452.)

[21] Stüper, J., *Untersuchung von Reibungsschichten am fliegenden Flugzeug*, Luftfahrtforschung, Vol. 11, No. 1, page 26, May, 1934. (Translated in N.A.C.A. Technical Memorandum 751.)

[22] Stephens, A. V., *Hot-Wire Experiments in Flight*, Journal of Applied Mechanics, Vol. 5, No. 3, page A-131, September, 1938. (Abstract of paper presented at Fifth International Congress for Applied Mechanics.)

[23] Clauser, Milton, and Clauser, Francis, *The Effect of Curvature on the Transition from Laminar to Turbulent Boundary Layer*, N.A.C.A. Technical Note 613, 1937.

[24] von Doenhoff, A. E., *A Preliminary Investigation of Boundary-Layer Transition along a Flat Plate with Adverse Pressure Gradient*, N.A.C.A. Technical Note 639, 1938.

PUBLICATIONS
OF THE
NATIONAL BUREAU OF STANDARDS GROUP
ON
TURBULENCE AND BOUNDARY LAYER

Technical Reports of the National Advisory Committee for Aeronautics

No.

231. *Investigation of Turbulence in Wind Tunnels by a Study of the Flow About Cylinders.* H. L. Dryden and R. H. Heald. (1926)

320. *The Measurement of Fluctuations of Air Speed by the Hot Wire Anemometer.* H. L. Dryden and A. M. Kuethe. (1929)

342. *Effect of Turbulence in Wind Tunnel Measurements.* H. L. Dryden and A. M. Kuethe. (1930)

392. *Reduction of Turbulence in Wind Tunnels.* H. L. Dryden. (1931)

448. *Improved Apparatus for the Measurement of Fluctuations of Air Speed in Turbulent Flow.* W. C. Mock, Jr., and H. L. Dryden. (1932)

497. *Computation of the Two-dimensional Flow in a Laminar Boundary Layer.* H. L. Dryden. (1934)

524. *A Turbulence Indicator Utilizing the Diffusion of Heat.* G. B. Schubauer. (1935)

527. *Air Flow in a Separating Laminar Boundary Layer.* G. B. Schubauer. (1935)

546. *The Effect of Turbulence on the Drag of Flat Plates.* G. B. Schubauer and H. L. Dryden. (1936)

562. *Air Flow in the Boundary Layer Near a Plate.* H. L. Dryden. (1936)

581. *Measurements of Intensity and Scale of Wind Tunnel Turbulence and Their Relation to the Critical Reynolds Number of Spheres.* H. L. Dryden, G. B. Schubauer, W. C. Mock, Jr., and H. K. Skramstad. (1937)

598. *Alternating-current Equipment for the Measurement of Fluctuations of Air Speed in Turbulent Flow.* W. C. Mock, Jr. (1937)

In Press. *Air Flow in the Boundary Layer of an Elliptic Cylinder.* G. B. Schubauer.

Publications Elsewhere

Turbulence, Companion of Reynolds Number. H. L. Dryden. J. Aero. Sciences, Vol. 1, page 67 (1934).

Frontiers of Aerodynamics. H. L. Dryden. J. Wash. Acad. Sci., Vol. 25, page 101 (1935).

Aerodynamics of Cooling. H. L. Dryden. Division T, Vol. VI of Aerodynamic Theory (J. Springer, Berlin, 1936).

The Theory of Isotropic Turbulence. H. L. Dryden. J. Aero. Sciences, Vol. 4, page 273 (1937).

Recent Developments of the Theory of Turbulence. H. L. Dryden. J. Applied Mech., Vol. 4, page A-105 (1937).

Turbulence Investigations at the National Bureau of Standards. H. L. Dryden. Proc. Fifth Inter. Cong. Appl. Mech. (1938).

The Effect of Turbulence on Transition in the Boundary Layer of an Elliptic Cylinder. G. B. Schubauer. Proc. Fifth Inter. Cong. Appl. Mech. (1938).

Discussion

THE second Wright Brothers Lecture entitled "Turbulence and the Boundary Layer" was delivered by Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division of the National Bureau of Standards, at the Pupin Physics Laboratory, Columbia University, at 3:00 p.m. on December 17, 1938. This lecture is an annual ceremony commemorating the first flights of Wilbur and Orville Wright at Kitty Hawk, North Carolina, on December 17, 1903. It is sponsored by the Institute of the Aeronautical Sciences through the "Vernon Lynch Fund."

Before the lecture the Council gave a small luncheon in honor of Dr. Dryden at the Columbia University Faculty Club.

The lecture was also given simultaneously at about 25 Institute Branches throughout the country.

The introductory remarks and the discussions following the lecture are printed below.

T. P. Wright

President of the Institute

I can think of no more fitting way to honor and perpetuate the pioneering work of the brothers Wilbur and Orville Wright than in the establishment of the Wright Brothers Lectures as an annual ceremony to be held on the anniversary of that first powered flight of man just 35 years ago today. On the occasion of this second Wright Brothers Lecture the Institute has sent the following telegram to Mr. Orville Wright: "On this thirty-fifth anniversary of the first flights by you and your brother Wilbur at Kitty Hawk the members of the Institute of the Aeronautical Sciences meeting at Columbia University to hear the second Wright Brothers Lecture given by Dr. Dryden send you greetings and best wishes for your good health and happiness."

Through the courtesy of Columbia University, Dr. Butler, and Prof. Pegram, we are again privileged to hold the Wright Brothers Lecture in this auditorium. I wish to again express the thanks of the Institute for the facilities placed at our disposal for meetings of this kind. The Institute has held all of its meetings in this building and this important assistance given our organization by the University is deeply appreciated.

Following the first Wright Brothers Lecture last year the late Edmund C. Lynch was so impressed by the importance and dignity of the occasion that he established the Vernon Lynch Fund in honor of his brother for the purpose of endowing the lecture.

Before introducing Dr. Dryden I shall ask Mr. Sherman Fairchild, one of the few men who knew Mr. Lynch intimately and who is responsible for exciting his interest in the Institute, to speak.

Sherman M. Fairchild

Last year I invited my friend Mr. Edmund C. Lynch to be my guest at the Institute's Honors Night Dinner. He saw the distinguished group of aeronautical specialists, including Mr. Wright and Colonel Lindbergh, and was greatly impressed with the dignity of the occasion. He turned to me and said that he might be interested in giving the Institute a fund and suggested that I have several proposals sent to him. The one he accepted was that of honoring the Wright brothers. He sent the following letter to Major Gardner, Secretary of the Institute.

Dr. Hugh L. Dryden

"Dear Mr. Gardner:

"So strongly am I of the opinion that the Wright Brothers Lecture will bring disclosures of advances which will be of practical benefit to aviation—that the Honors Night plan of commemorating this anniversary is so worthy of the occasion—that I believe the Institute should continue this work.

"With this in view I desire to make a contribution to the Institute, the principal of which is to be held intact and the income therefrom applied annually toward the accomplishment of this purpose.

"This contribution is in commemoration of my brother, Mr. Vernon Lynch.

"With this in mind and as my contribution I enclose herewith 125 shares of the common stock of Melville Shoe Corporation and 185 shares of the common stock of Peoples Drug Stores, Inc., of the present market value of $10,335.00.

Sincerely yours,
EDMUND C. LYNCH"

The income from the Fund during the first year has amounted to $636.88. Lecturers from abroad are given an honorarium of $500 and lecturers from the United States receive $250. The Fund, therefore, will carry the full expense of these lectures.

Mr. Lynch died suddenly on May 12th in London, just before his fifty-third birthday. He was born in Baltimore and graduated from The Johns Hopkins University in 1907. By 1911 he became interested in investment banking and in 1915 formed the firm of Merrill, Lynch and Company, which was the first investment firm to interest itself in the chain store industry. During the War, Mr. Lynch served with the cavalry and after the War was made a Major in the U. S. Signal Reserve Corps.

Mr. Lynch was one of the most reticent men I ever met. We cannot even find a good photograph of him. He wanted this endowment to center about his brother, Vernon Lynch.

Vernon Lynch was also a graduate of The Johns Hopkins University, having received his academic degree in 1914 and his Ph.D. in 1918. He was an assistant in Physiology at the University and only a few months after receiving his doctorate degree and two months after his marriage he was killed in a motorcycle accident at the age of 26.

The Johns Hopkins Alumni Magazine in his obituary said:

"Vernon Lynch was a typical student of the 'old Hopkins' type. He was known and esteemed, not only by all of his classmates, but by practically every member of the then small and closely knit student body. Conscientious in everything he did, he was one of those sincere and unostentatious men whose very reticence endows them with a certain power of attraction. That his merits were quickly recognized is evidenced by the fact that he received his appointment as an assistant in Physiology before he had gained his degree of Doctor of Philosophy. In University and Class activities he was always a leader and always to the credit of his Alma Mater. Immediately after receiving his degree he was called into government service at Washington where he did excellent work in the capacity of physiologist in the Bureau of Mines. Dr. Lynch was a man from whose career great honor would have certainly accrued to his native city and to the University at which he received his training."

In addition to the Vernon Lynch Fund which the Institute administers, Mr. Edmund C. Lynch also left $50,000 to The Johns Hopkins University to establish the Vernon Lynch Memorial, the income to be used for the study of arthritis.

Speaking for the Council at this Second Lecture under the Vernon Lynch Fund, I wish to express their assurance that every possible effort will be made to make the Lectures and other celebrations of the Wright Anniversary not only worthy of the interest of Mr. E. C. Lynch but also through contributions to aeronautical knowledge, to cause the memory of Vernon Lynch to be associated with progress in the art and science of aeronautics.

I take pleasure, Dr. Dryden, in giving you an honorarium of $250 from the Vernon Lynch Fund.

T. P. Wright

Thank you Mr. Fairchild. We are all indebted to Mr. Lynch and to yourself for your efforts on behalf of the Institute in honoring the Wright brothers on this occasion.

We all remember the occasion a year ago today when Prof. B. Melville Jones delivered the first Wright Brothers Lecture. His masterful presentation of his interesting and important investigations on "Flight Experiments on the Boundary Layer" gave this series an impetus and prestige which I know will be ably continued by Dr. Dryden's lecture today.

The Institute is using this lecture to inaugurate a program of "Simultaneous Branch Lectures" at the Institute Branches throughout the country. At each branch the lecture is being read by a member who is conversant with the field. In this way Dr. Dryden's audience is not limited to those assembled here.

Dr. Dryden is a distinguished physicist and his many important contributions to the science of aeronautics are well known. He is Chief of the Mechanics and Sound Division at the National Bureau of Standards. His investigations in the field of turbulence are of both classical and practical importance. The subject of the lecture is closely allied to that of Prof. Jones and may be considered as a continuation of the discussion on this timely topic.

Dr. George W. Lewis

National Advisory Committee for Aeronautics

Because the National Advisory Committee for Aeronautics is in some measure a party to the work so ably conducted and described by Dr. Dryden, I feel constrained to pass over the many complimentary remarks that come to mind, with reference to this the second Wright Brothers Lecture. The National Advisory Committee has been privileged to cooperate with the National Bureau of Standards in attacking fundamental problems of fluid mechanics under Dr. Dryden's supervision, and I wish to take this occasion to express the Committee's sincere appreciation of the work being done by Dr. Dryden and his colleagues along these lines.

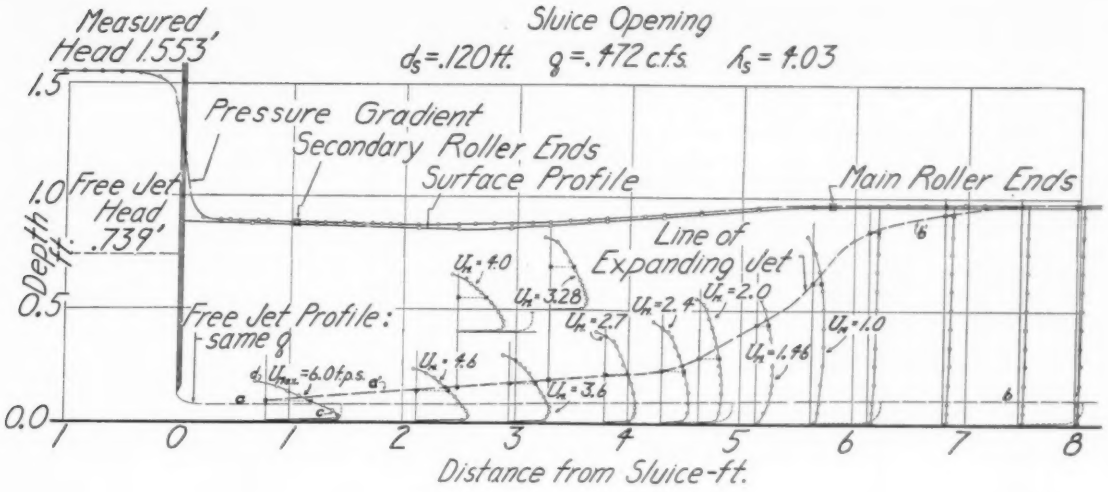
The branch of fluid mechanics treated in the lecture has in recent years become of sufficient importance to merit very thorough and extensive investigation and, as Dr. Dryden has indicated, the problem has been subdivided to facilitate more rapid execution of a broad fundamental investigation. The attention of the Committee's laboratory at Langley Field has been directed mainly toward the more immediate practical aspects of the subject and has been carried on largely under the supervision of Eastman N. Jacobs in connection with airfoil research. I have therefore requested a statement from Mr. Jacobs who has submitted the following comments:

"It seems sufficiently evident that this fundamental work has contributed much and will continue to contribute largely to technical advances in aeronautics. As Dr. Dryden has indicated, however, the weak part of present foundations is lack of knowledge of the transition phenomenon. Both he and Professor Jones have emphasized the note of interrogation, pointing out that the work to date tends to bring forth more questions than it answers.

"We would like to see the problem of transition simplified to such an extent that some definite practical information can be obtained. Some steps are being taken in the right direction; for example, Dryden's combination of the two controlling factors associated with turbulence into the single Taylor parameter. We were particularly encouraged, moreover, to note his reference to the turbulence of the atmosphere as substantially zero. This is, for practical purposes, certainly true at times. Consequently, zero turbulence may for the present be taken as a fundamental standard reference condition. We may thus reduce many problems to those of an "aerodynamically smooth flow" which, like the "aerodynamically smooth" surface, may not be entirely free from disturbances, but which may be considered to be substantially free from effects of residual unsteadiness.

"The research at Langley Field has therefore been concerned primarily with this underlying problem: Transition as it may be simplified by eliminating the generally undesirable turbulence and surface roughness factors. Two others, pressure gradient and curvature, might also have been eliminated by the use of flat plates, but these factors are of a different character. Not only are difficulties encountered at the nose of a flat plate, but practical solutions without the inclusion of the pressure and curvature factors would be of limited practical interest because the attendant effects are frequently desirable. Although I hope we are simplifying the practical problem to some extent, I must also end on a note of interrogation. We have found that rising pressures frequently do not, as suggested in the conclusion drawn from Fig. 13 (p. 97), cause almost immediate transition. In fact, laminar flow sometimes continues to a point behind that of laminar separation, but we also have tended to abandon the hope that transition may be predicted in terms of local conditions. Is it possible, however, that the general conditions over the surface are of primary importance only as they affect the boundary-layer thickness and the character of the boundary-layer velocity profile at the station under consideration?"

At the present time there seems little further to add. Thus far the Wright Brothers Lectures have been novel and unusual in the respect that they propound a question rather than present an answer. Past experience has indicated time and again that a thorough knowledge of the question was a long step toward finding the answer, and in this respect the lectures constitute a highly constructive and progressive contribution to aeronautical science. Knowing as we do the Wright brothers' devotion to progressive and constructive research, I believe that in



the presentation of this lecture no more appropriate expression of our regard for them could be found.

Prof. Boris A. Bakhmeteff

Columbia University

I shall discuss a few aspects under which the boundary layer and its relation to turbulence in the adjacent media appears in hydraulic engineering. Contrary to aeronautics, flow in hydraulic practice is usually confined by narrow solid boundaries, the problems of "established turbulence" gaining particular importance. It is not always realized, however, that the established flow pattern, as in a pipe, actually develops out of a boundary layer, initiated at the entrance section, and which gradually spreads and ends by "filling up" the whole cross section of the conduit. It appears further that, whether the resulting established flow in the conduit will be laminar or turbulent (eddying), in the accepted sense, depends upon whether the boundary layer will complete its expansion before or after the "transition" occurs.

A most important of boundary layer problems, is also the expansion of live fluid veins in submerging tail water, as it occurs at the foot of dams, below sluice openings, in the "mixing" chamber of jet pumps, etc. In all such cases a boundary layer zone is developed on both sides of the initial "discontinuity surface," separating the live jet from the surrounding fluid. The boundary layer on one side eats into the live jet, and on the other gradually spreads into the surrounding tail water, adding momentum to its motion.

Tollmien, Kuethe, and others have most successfully investigated the simpler case of a potential jet spreading in infinite media. In hydraulic practice, however, a "near potential" jet comes into contact with what is termed a "roll," meaning a dead water space of more or less constant form, within which water is engaged in a highly agitated circulatory motion. Obviously the state of turbulent agitation in a "roll" is exceptionally high, with the "mixing lengths" exceeding by far anything observed in normal established patterns. Under such conditions, the turbulent "eating" into the potential jet and the expansion of the boundary layer zone should occur far more rapidly, and with a far greater angle, than in the case of a jet in infinite media.

The phenomena is illustrated by the figure above, obtained by Mr. F. Ebetsch in the Fluid Mechanics Laboratory at Columbia University.

Line *ab* relates to free efflux of the jet from under the sluice, the successive velocity profiles taken with a pitot tube and shown by a broken line features the gradual expansion of the boundary layer near the bottom. Line *a'b'* represents the jet surface for the same discharge in submerged condition. The space between *a'b'* and the free surface is the "roll" region. The velocity profile *cd* shows that as near the sluice opening as one could measure, turbulence from the "roll" has penetrated practically into the cross section of the jet, with the exception of the very thin zone of the friction boundary layer near the bottom, which seems to offer the greatest resistance to velocity change.

Dr. W. F. Durand

Stanford University

The accidents of travel from the Pacific Coast have not permitted me to see the advance proof of Dr. Dryden's paper, so that I cannot hope to add anything of technical value to the discussion. I am glad, however, of the opportunity of voicing what seems to me the extreme importance of fundamental studies of the character discussed in this paper.

It is not too much to say that we have passed beyond the point, in our development of the domain of fluid mechanics, where the classical theory, based on the properties of the so-called perfect fluid can be of further significant aid, especially in respect to those factors which affect the energy reactions between a solid and a fluid in relative motion.

The influences of viscosity and of compressibility—the two specifications in which actual fluids differ from the ideal medium—must be brought into the picture, and the literature of recent years shows the eager response which students of fluid mechanics are making to this demand.

Of these two specifications, viscosity, as evidenced in the phenomena of turbulent flow, has perhaps the larger immediate importance, though recent advances in speed have had the result of bringing compressibility also into the foreground of the picture.

The Institute of the Aeronautical Sciences is peculiarly fortunate, through the munificent "Vernon Lynch Fund," in being able to provide the "Wright Brothers Lectures," a series named in honor of those pioneers in the science and art of aviation, who, 35 years ago, showed to us the pathway which has led to the marvelous developments of the present day.

This series of lectures provides thus a forum for the discussion of the important basic problems of aeronautical science, and it has seemed particularly timely that the first two of these lectures should have dealt with the important field of phenomena involved in turbulent flow.

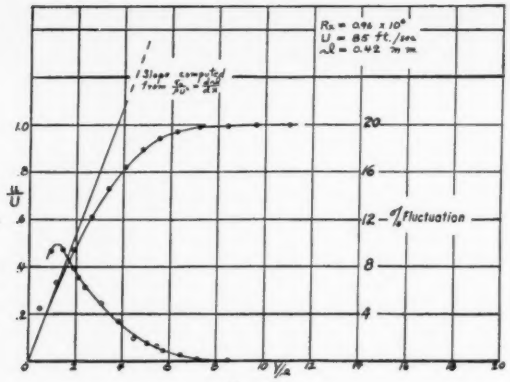


FIG. 1.

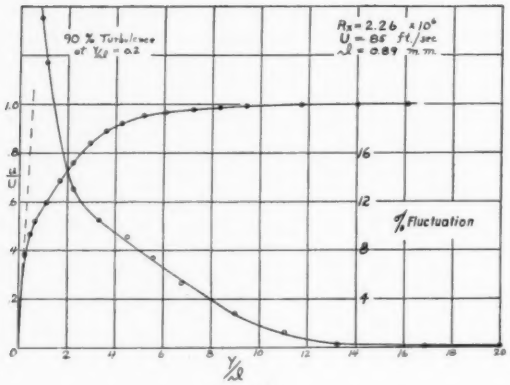


FIG. 2.

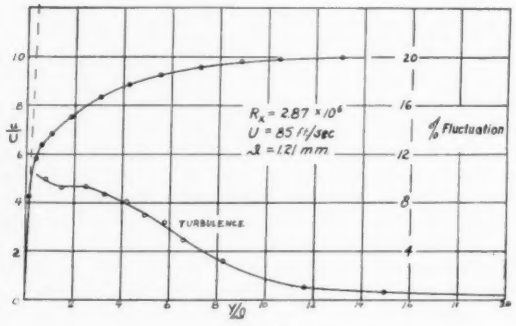


FIG. 3.

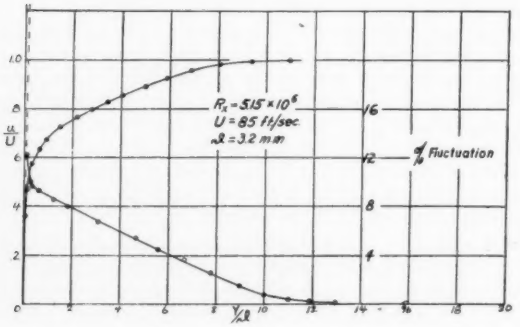


FIG. 4.

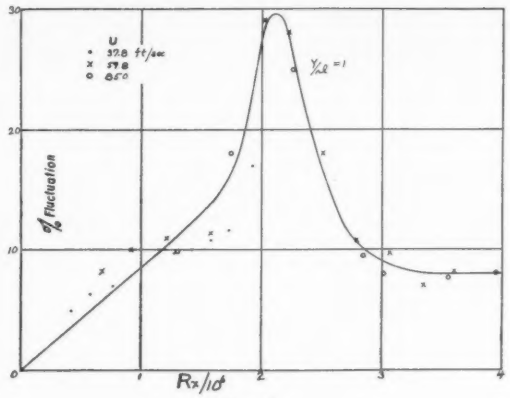


FIG. 5.

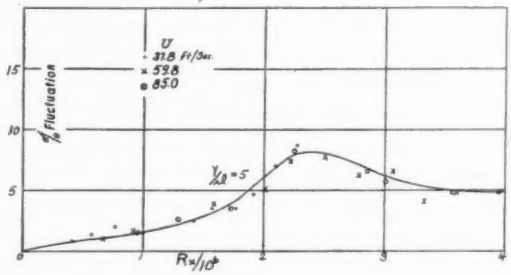


FIG. 6.

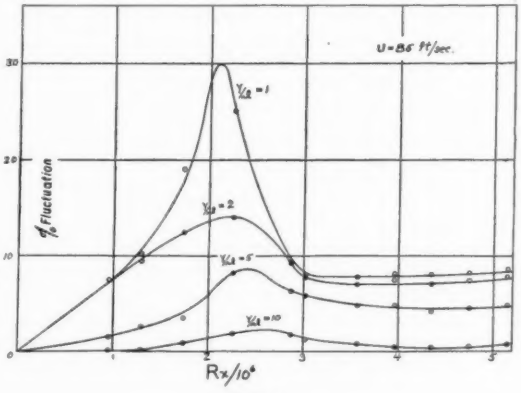


FIG. 7.

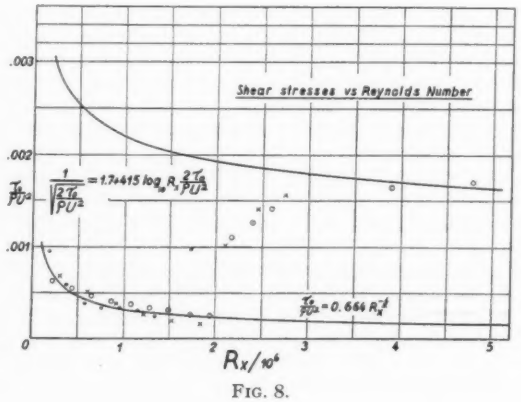

Shear stresses vs Reynolds Number
$\frac{1}{\sqrt{\frac{2\tau_0}{\rho U^2}}} = 1.7 + 4.15 \log_{10} R_x \sqrt{\frac{2\tau_0}{\rho U^2}}$
$\frac{\tau_0}{\rho U^2} = 0.664 R_x^{-\frac{1}{2}}$
$R_x/10^6$

FIG. 8.

We remember, I am sure, with deep interest and appreciation the occasion of a year ago, when we listened to the brilliant address of Prof. Melville Jones, and I feel that the Institute is to be congratulated on its choice of a speaker, among American students in this field, to continue the discussion of this important subject.

The paper which we have just heard, will, I am confident, take its place among the important contributions to our better understanding of these intricate problems involved in our study of turbulence and turbulent flow.

Dr. J. C. Hunsaker

Massachusetts Institute of Technology

I have only praise for the clear and precise definitions used by Dr. Dryden to distinguish the physical phenomena he has been discussing, but I should like to raise a question as to the possible confusion that could result from a general use, outside the field of boundary layer mechanics, of his definitions of laminar and eddying flow. Dr. Dryden certainly has the right and the duty to define his own terms. My doubts are aroused by the term "eddying flow" to describe a flow with irregular velocity fluctuations above an arbitrary cut-off frequency, formerly called fully developed turbulence. We have all learned to use the term "eddying flow" to describe the flow in the wake of an obstruction, a "vortex street," or for any flow in which regular eddies are clearly manifest. Such a flow could give rise to irregular velocity fluctuations, as could also a wavy layer in laminar flow. I believe the minimum of confusion will arise if the term "turbulence," supplemented by the usual qualifying adjectives, be used for all irregular flow patterns, with or without correlation, where the lateral exchange of matter or momentum is accomplished by the fluid motion, rather than primarily by viscosity or molecular motion. This seems to have been the practice of the participants in the Turbulence Symposium held at the Fifth International Congress for Applied Mechanics.

Dr. Dryden has mentioned the comprehensive program of the National Advisory Committee for Aeronautics. A part of this program, being handled in Cambridge by my colleague, Professor H. Peters, is concerned with the effect of pressure gradient on the boundary layer. He has succeeded in developing a special two-dimensional wind tunnel in which the isotropic turbulence is less than 0.2 percent. One side of the tunnel is a flat plate 10 ft. long with a suction slot at its leading edge to remove the air made turbulent by its passage down the tunnel walls. The curvature of the opposite wall is adjustable to permit variation of the pressure gradient.

Our first experiments, made with zero pressure gradient, are in confirmation of Dr. Dryden's results. Our hot wire anemometer technique for measuring mean and instantaneous velocities is substantially identical with the equipment originally developed by Dr. Dryden, to whom we are grateful for this beautiful tool of investigation.

Fig. 1 shows the mean velocity profile in the laminar region, with a percentage velocity fluctuation curve indicating the flow is in wavy lines. The y coordinate is made non-dimensional by division by the "momentum thickness" of the layer: $\theta = \int_0^\delta \left[\frac{u}{V} - \left(\frac{u}{V}\right)^2\right] dy$. The percentage fluctuation is $\sqrt{\overline{u'^2}}/u$, where u' is the deviation of the instantaneous velocity from the mean velocity u at distance y out from the wall.

Fig. 2 shows the state of affairs in the transition region. Note that the percentage fluctuation near the wall is of very great magnitude and reaches 90 percent at $y/\theta = 0.2$. Evidently this fluctuation approaches 100 percent when $y = 0$, and separation has already taken place before turbulence sets in.

Figs. 3 and 4 show corresponding conditions farther downstream, where the velocity profile is characteristic of fully developed turbulence. The percentage fluctuation, however, is much lower than in the transition region.

The percentage fluctuation appears to us to be a critical parameter to disclose the nature of the flow, and to locate the point of transition.

Figs. 5 and 6 give the percentage fluctuation in terms of the Reynolds Number for three tunnel speeds at each of two distances out from the wall. For these experiments, all variables except R_x are constant (*e.g.*, equal isotropic turbulence in the general flow, equal smoothness of plate, equal entrance conditions, equal pressure gradient (nil), equal curvature (nil), etc.).

Fig. 7 is a similar plot, at one tunnel speed, for four distances y. Note that data for each point indicate the transition point at R_x above 2,000,000 by a marked rise in percentage frequency. This plot seems to me to constitute conclusive evidence that transition is a function of Reynolds Number. Professor Jones was somewhat doubtful, last year, as to the validity of such a view, but his data could not be arranged to hold all other possible variables constant.

I think it only fair to point out that Dr. Dryden with characteristic modesty, has avoided stressing the fundamental importance to engineers of his work and that of the others, such as ourselves, who are using his technique.

The location of the transition point permits the practical computation of drag for wings and bodies free from separation. Knowledge of the effect of wind-tunnel turbulence enables wind-tunnel data to be applied to design with less risk of unpleasant surprises. The technique of locating transition gives a tool for the study of means to delay its occurrence, and hence greatly to reduce drag. This is an open road for future research of great practical promise.

The boundary layer is the key to all the forces that act on a structure, and transition and separation phenomena are the essential elements of the problem of lift and drag. To show the engineering application of knowledge of the transition point, Professor Peters has plotted on Fig. 8 the shear stresses computed from his measured velocity profiles. The same plot shows, as full lines, the calculated values for a smooth plate according to the accepted formulae there quoted. The experimental data for R_x between 2,000,000 and 3,000,000 fall between the curves for laminar and turbulent flow, confirming the transition inferred from the plot of percentage fluctuation (Fig. 7).

It is encouraging to view such a plot and to speculate on the very good reductions in drag that will be possible when we learn how to retard the transition point and so to get a larger proportion of wing area subjected to low drag laminar flow.

T. P. Wright

Curtiss-Wright Corporation

Referring to the slides which Dr. Hunsaker has just shown, I would like to call attention to the practical importance which it could be anticipated would result from the studies of boundary layer flow, as so ably discussed by Dr. Dryden. In comparing the relative drag coefficients when the flow is laminar as against those which maintain for turbulent flow, attention is called to the great disparity of the two curves, the former giving values only about one-ninth of the latter. It follows that if the transition point can be made to move aft on all wetted surfaces of the airplane, from say 5 percent of the chord from the leading edge, as at present, to 30 percent, the skin friction drag would be reduced by approximately 25 percent. Further, as skin friction drag represents over 50 percent of the total drag of modern airplanes it becomes apparent that really important drag reductions with resultant speed increases would be attained. Studies such as those of Dr. Dryden's may well point the way to the practical attainment of such results.

Aircraft Engine Power Estimation from Intake Manifold Density

THOMAS B. RHINES, *United Aircraft Corporation*
PIETER W. SCHIPPER, *Commonwealth Aircraft Corporation*

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SUMMARY

A method of estimating engine power output in flight by means of calibrations based on the density of the fuel-air mixture in the intake pipe is described. Comparison of this method with the conventional manifold-pressure calibration is made, and test data taken with a torque indicator in flight are used to indicate the relative accuracies of the two methods. The comparison shows that there is little to choose between the two methods at the present stage of development of the newer one. However, improvement of the density method through advances in test technique is probable, because its basis is fundamentally sound. The manifold-pressure method is not on such a firm basis, so further advances with it are unlikely.

IT IS common practice in flight tests, transport operations, and in other flying activities to use the pressure of the fuel-air mixture in the intake manifold and the temperature of the air entering the carburetor for indication of the engine power output. Although this method of estimating power has been generally accepted for some time, there is much evidence to indicate that its accuracy is not all that could be desired. In this paper a new method, in which power is related to the density of the fuel-air mixture as it enters the cylinders, is described and compared with the conventional method. It has in the past been difficult or impossible to evaluate such methods from tests with engines in actual flight operation, but now the availability of an accurate torque indicator for use in flight has opened opportunities for much needed research in this direction.[1]

One of the principal weaknesses in the manifold-pressure and carburetor-air-temperature method of estimating engine power lies in the fact that the characteristics of the charge in the induction system at the carburetor do not necessarily bear any direct relation to those of the charge as it enters the cylinder. There are many opportunities for changes to take place in the temperature of the air or mixture after it has entered the carburetor, and these changes will not always be the same under different operating conditions or with different installation arrangements for a given type of engine. After the intake air enters the carburetor it experiences a drop in temperature due to the vaporization of the liquid fuel which is mixed with it, and this mixture is then supplied with heat as it passes through the supercharger. From the supercharger outlet to the intake port on the cylinder there may be a further change due to heat transfer through the intake pipes.

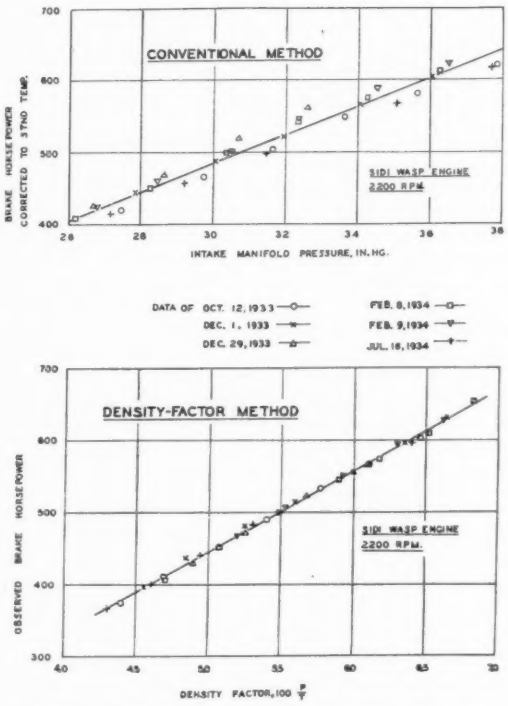


FIG. 1. Results of dynamometer tests on wasp engine.

THE DENSITY-FACTOR METHOD

Recognition of the presence of so many disturbing factors in the conventional method for estimating engine power led to a consideration of other methods which might give more satisfactory results. It was suggested that since the density of the fuel-air mixture in the intake pipes has a direct relation to the weight of charge drawn into the cylinder, it should be a reliable measure of the indicated horsepower developed by an engine. If suitable indication of the intake-air density could be obtained, this indication should also serve as a measure of engine brake-power output at a given engine speed, because the friction and pumping losses in the engine could satisfactorily be accounted for in dynamometer calibrations to show the relation between the intake-air density and the power output.

To evaluate the possibilities of this proposed method, a series of tests was conducted in 1933 and 1934 in which an engine was periodically run on a dynamometer test stand, and measurements were made of its power

output and of the factors necessary to prepare calibration curves both on the conventional manifold-pressure basis and on the new intake-density basis. The tests were extended over a period of about nine months, so that a reasonably wide variety of atomspheric conditions might be experienced. It was expected that a comparison of the irregularities resulting from changes in cooling-air and carburetor-air temperature might serve as an indication of the comparative values of the two methods. The engine used was reserved for this work exclusively, in order to avoid changes in its mechanical condition from modifications for other tests. The tests, on a Wasp engine, were begun in October, 1933, and concluded in July, 1934, with results as indicated in Fig. 1. For the conventional method the observed horsepowers were corrected to standard conditions in accordance with the assumption that the power output was inversely proportional to the square root of the absolute temperature of the air entering the carburetor. The customary corrections for humidity were applied to the results of the conventional method and also to those of the new density-factor method. On the latter basis the observed power, rather than a corrected power, is plotted against a "density factor." This factor is a number equaling 100 times the ratio of absolute intake pressure in inches of mercury to absolute intake temperature in degrees Fahrenheit. Although the constant used here is arbitrary, the density factor is directly proportional to the density of the intake mixture at the point of measurement, which in this case was the upper end of the intake pipe just ahead of the intake port and valve.

An inspection of the two curves in Fig. 1 shows the improvement resulting from the use of the proposed method. The density factor appears to account adequately for the influences of all of the variables involved in the test stand work. Some concern was felt, however, over the fact that the ranges of the variables encountered were by no means as large as in flight, but there was available at that time no suitable equipment for extending the ranges beyond those for the ordinary atmospheric conditions at sea level.

This first comparison indicated that there were possibilities for the new method of power estimation under part-throttle conditions, and the form of presentation of the data was such as to make possible a prediction of the output at full throttle under standard air conditions. The density-factor method of plotting engine calibration results is, strictly speaking, concerned only with the power section of the engine, because all measurements of the characteristics of the intake charge are made after its passage through the carburetor and supercharger. It is desirable, however, to be able to indicate the expected power at full throttle with standard-air conditions at the carburetor air intake, as there appear to be no grounds for assuming the use of some arbitrary set of standards for conditions

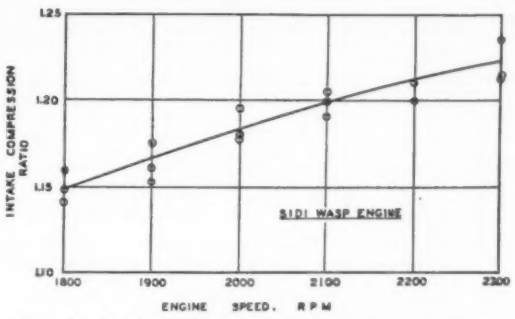


FIG. 2. Intake-system compression ratio from dynamometer tests.

within the intake pipe at the cylinder. It is apparent that suitable standard full-throttle curves can be obtained only through study of the relations existing between conditions in the carburetor entrance and in the intake pipes.

A series of tests showed that the ratio of air density at the carburetor entrance to intake density at full throttle is, for practical purposes, dependent only on the engine speed under normal sealevel conditions with a gear-driven supercharger. The use of this compression ratio seems especially attractive in view of the fact that it can be determined in flight almost as easily as on the dynamometer with only the usual pressure and temperature measuring instruments. The dependence of the compression ratio on engine speed alone is of course limited to circumstances under which the characteristics of the carburetor-blower system are unchanged. The installation of a hot spot between the carburetor and blower, or any modification which will change the blower performance, will obviously cause changes in the intake compression ratio.

This point is important in connection with supercharging systems other than the single-speed, gear-driven type. With a two-speed blower, it would be necessary to make the calibration and compression-ratio tests twice, and thus to treat each blower speed as a separate and independent case. With exhaust-driven turbo-superchargers, the problem is undoubtedly more complicated, as the changes in back pressure and the highly flexible supercharger drive introduce additional variables. While no work has been done with the density-factor method on turbo-supercharger systems, it is probable, because of the basic nature of the method, that suitable means to cover such cases can be devised.

The results shown in Fig. 2 are typical of those for the gear-driven type of blower. The measurements were made with the Wasp engine on the dynamometer to determine the intake-system compression ratio at full throttle with various speeds. The ratio can be expressed by $C = (P_i/P_c) \times (T_c/T_i)$ where the subscripts c and i denote conditions at the carburetor entrance, and in the intake pipe, respectively.

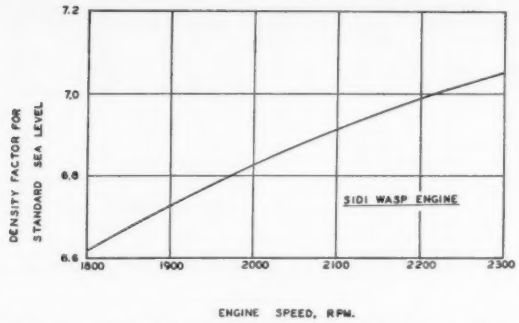


FIG. 3. Density factors for standard sealevel conditions at full throttle.

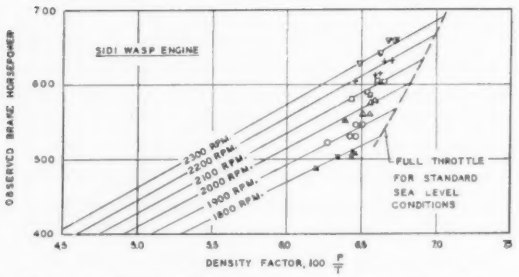


FIG. 4. Density-factor power curve showing full-throttle points.

For standard sealevel conditions (29.92 in. of mercury pressure and 59°F.) a "standard sealevel atmospheric density factor" can be calculated, and if this factor is multiplied by the compression ratio at any speed the result will be the intake density factor for that speed. The results of this process are shown in Fig. 3, which represents the density factors which should exist in the intake pipes with standard sealevel conditions outside the carburetor.

With the standard sealevel density factors thus established, it is a simple matter to plot the corresponding full throttle power from curves such as those shown in the lower part of Fig. 1. Fig. 4 contains a series of such curves for various engine speeds with a full throttle line drawn through points on each curve at the standard density factors indicated by Fig. 3. The test points on Fig. 4 show the actual values for power and density factor obtained at full throttle in the test runs, and it is to be noted that these all show the effects of the high carburetor-air temperatures and low intake pressures resulting from the use of the particular air-supply system installed with the dynamometer.

In the case of a highly supercharged engine, it would be undesirable to attempt to find the full-throttle, sealevel, intake compression ratios by direct tests at full throttle, as the power output would be excessive. Under these conditions the powers may be kept within the necessary limits by throttling the air supply ahead of the carburetor and, at each speed, the compression ratio may be obtained for a variety of

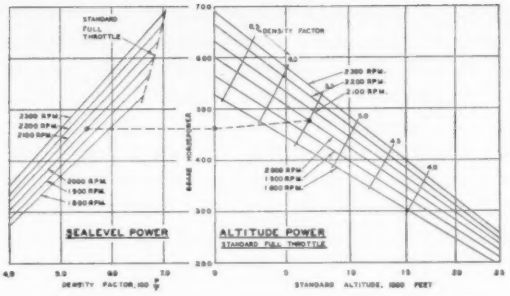


FIG. 5. Altitude power curves constructed from dynamometer test results.

degrees of throttling. From the results, a curve of compression ratio against density ahead of the carburetor may be extrapolated to standard sealevel density to find the appropriate value for compression ratio. The extrapolation is an easy one, because the compression ratio varies only slowly with change in density ahead of the carburetor. In this test, it is desirable to keep the temperature of the intake-air supply as near as convenient to that for standard sealevel, as the compression ratio is somewhat influenced by temperature, although for usual variations the resulting error will be well within the general precision of the test.

POWER AT ALTITUDE

From the sealevel power curve obtained by either the manifold-pressure or the density-factor method, it is necessary to predict the engine performance at altitude for use in flight work. The variation of full-throttle engine power with altitude is naturally not affected by the form of analysis used to establish the sealevel full-throttle power, and it is, therefore, suitable to use any accepted relationship for this variation. From the results of the sealevel test on the Wasp engine, altitude curves were prepared in accordance with the relationship described by Gagg and Farrar.[2] These full-throttle curves are shown in the right-hand portion of Fig. 5.

For prediction of part-throttle power at altitude, it is desirable to know the full-throttle density factors which will obtain under various conditions, and these factors can preferably be found in actual flight tests, although ground tests with the intake air throttled ahead of the carburetor to simulate the reduction in density at altitude may give approximately correct results. The form of the analysis involves the use of the carburetor-blower system compression ratio in much the same manner as it was used for finding the full-throttle density factors at sealevel. While the compression ratio does not vary a great deal with altitude, or with reduction in density ahead of the carburetor, the change is large enough at high altitudes to be worth consideration. In a typical case, the reduction in compression ratio at constant speed

at an altitude of about 20,000 feet as compared with sealevel was of the order of 3 or 4 percent. The necessary curve of compression ratio against density ahead of the carburetor can be prepared from actual flight tests, because, as mentioned above, only the usual pressure and temperature measurements are necessary. Fig. 5 shows the full-throttle density factors under standard conditions, as predicted for the test engine.

For part-throttle operation at altitude, the desired power values can be found on a line joining the corresponding sealevel part-throttle power and the full-throttle power at whatever altitude it may occur. An example is indicated by the dashed line in Fig. 5, which for a density factor of 5.50 and an engine speed of 2000 r.p.m. shows 461 hp. at 2000 feet, 470 hp. at 4000 feet, and up to 476 hp. at about 7000 feet, which is the maximum altitude to which 5.50 density factor can be maintained at 2000 r.p.m. under standard conditions.

The curves of engine performance at full throttle at altitude are necessarily plotted for standard air conditions, which means that they will not apply in detail for operation with carburetor-air temperatures or pressures differing from those in the standard atmosphere. The curves can, however, be used with sufficient accuracy, if the altitude is taken as that determined by the density of the air just ahead of the carburetor. Thus, if the carburetor air conditions at an actual pressure altitude of 5000 feet were affected by hot air and by air-scoop losses so that the carburetor-inlet density altitude was 6000 feet, the latter figure should be used in entering Fig. 5 to find the full-throttle power and density factor. The resulting error in this method is represented by the small change in power due to the difference in back-pressure effects, and this error can be considered to be negligible. For part-throttle power under non-standard conditions, the curves can be used without modification, as the throttling condition is defined by the density factor. Whether its value is the result of standard or non-standard conditions ahead of the carburetor is immaterial.

Technique of Density Measurement

The results of the first laboratory tests made to study the new density-factor method were very encouraging, especially in view of the recognized inadequacy of the conventional power curves on the manifold-pressure basis. The density-factor method appeared to be one that was basically sound, in view of its intention to measure the characteristics of the charge at a point where those characteristics would be definitely related to the power output. Some concern was felt, however, regarding the accuracy of the temperature measurements in the intake pipe or intake port which were required to find the density factor. Such measurements might be made at the blower rim, in the intake port close to the valve, or at any intermediate position in the intake pipe. There was evidence that readings at the blower rim were unsatisfactory, probably because the characteristics of the mixture were affected by heat exchange through the intake pipes, while at the other end of the system the measurements near the intake valve seemed to be influenced by heat conducted or radiated from the cylinder head. There were indications also that errors were introduced at the intake port by blow-back of exhaust gases past the intake valve.

Dynamometer tests were conducted to study these questions but the results were not in themselves considered adequate definitely to prove that the density-factor method was without serious errors. The dynamometer work gave clear indications in many cases, but because it was known that the changes in installation details between the ground tests and actual flight can change the power output in many ways, it was felt that flight experience was necessary to prove the worth of the new method.

In any of the locations in the system between the blower and the cylinder, the presence of liquid fuel might be expected to give difficulty. An attempt was made to study this question by comparison of calculated and measured temperature drops in the intake system of a single-cylinder engine. From this work, there was a rough indication that almost all of the fuel must have vaporized by the time the intake port was reached, but this conclusion appeared to be in conflict with visual observations which had been made through glass intake pipes in other experimental work. As a possible solution for this difficulty (if the difficulty exists), tests were made using a thermocouple which was located within a shield so that liquid fuel would not impinge directly upon it, but under various test conditions the temperatures measured with this device were found to differ by only a few degrees from those with a normally exposed thermocouple junction. It, therefore, seemed unlikely that any upsetting disturbances could be eliminated by this means.

Flight-Test Comparisons

Prior to the development of the torque indicator, there was available no convenient method for checking in flight the predictions of engine power made by dynamometer tests at sealevel. Both the conventional manifold-pressure method and the density-factor method were used in a great many flight tests for the purpose of estimating power, in the hope that a large body of data accumulated in this way would give some definite clues as to the relative merits of the two methods. In some of the flight tests, the relationships between airplane speed and estimated engine power seemed to favor the density method, while in other instances more consistent results were obtained using the conventional power curves. In the same type of work there seemed to be no clear

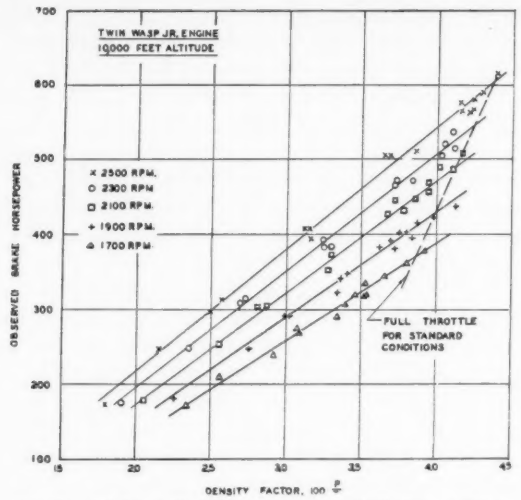


FIG. 6. Flight calibration by torque indicator plotted on the density-factor basis.

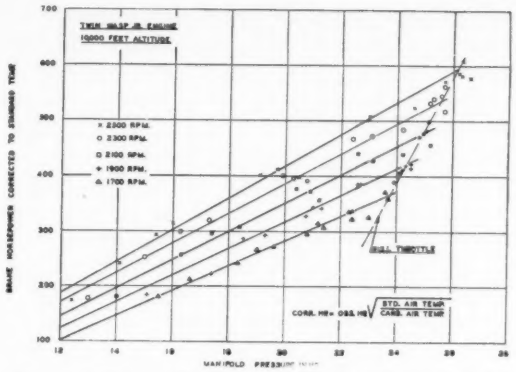


FIG. 7. Flight calibration by torque indicator plotted on the conventional manifold-pressure basis.

indications as to the best location for measurement of the intake-density factor. As a result, some of the flight-test engineers preferred to use the density-factor and conventional methods simultaneously and average the results to obtain estimated power. In spite of considerable experience in the use of the density-factor charts, no very definite conclusions could be drawn from tests under these conditions.

When the torque indicator became available for flight tests, it was possible to undertake a systematic investigation to compare the actual merits of the two methods without the introduction of any assumptions which might invalidate conclusions from the tests. The type of testing done in flight with the torque indicator included primarily the measurement of actual powers at various altitudes, with various engine speeds, and with various throttle openings. It was thus possible to obtain at any altitude an engine calibration which was identical in form with those which had customarily been made at sealevel on a dynamometer. Such tests were run with measurements suitable for later use of either the density-factor or the manifold-pressure method for analysis of the results. An example of the type of curve obtained is shown in Fig. 6, which represents a calibration for a Twin Wasp Jr. engine at 10,000 feet altitude, with the observed powers plotted against the intake density factor as measured in the intake port. The procedure for obtaining this figure was substantially identical with that for Figs. 1 and 4. In Fig. 7 the same test results are plotted on the conventional manifold-pressure basis with power corrected in accordance with the temperature of the air at the carburetor inlet. An inspection of these two figures, which represent conditions with best-power mixture ratios for an engine without a low-drag cowl, indicates that there is little to choose between the two methods from the point of view of scattering of the test points, although some slight preference for the density-factor basis might be justified.

Prior to the flight tests of this engine, the usual calibration test had been made on a dynamometer at sealevel, from which power curves on the density-factor basis and others on the conventional manifold-pressure basis had been prepared. Comparison could then be made between the actual powers as measured in flight and those which would be estimated through normal use of the two methods. Such comparisons are shown in Figs. 8 and 9 in which the curves for power by the torque indicator are taken from Figs. 6 and 7. These figures seem to indicate a definite superiority for the manifold-pressure basis, but in fairness to the newer method it must be mentioned that the curves shown represent only one test condition out of a great number which were covered in the work. Similar calibrations were made at a number of altitudes up to 20,000 feet and still further work was done with a low-drag cowl installed around the engine. While these particular samples show better results with the manifold-pressure curve, there were others which individually indicated superiority for the density-factor basis.

A more adequate general comparison is available in Figs. 10 and 11, which show the measured and estimated powers for a large number of test points which were obtained at various altitudes, engine speeds, for both full- and part-throttle operation. Results for conditions both with and without cowl are shown. A comparison of the two sets of data indicates, first, that the location of the mean curves for the density-factor method is better, but the dispersion of the test points is somewhat greater. From this it might be concluded that for a series of tests involving a large number of conditions, better average results would be had from the density factors, but for a single isolated observation the chances of a large error might be less if the manifold-pressure and carburetor-air-temperature criterion were used. As a point definitely favoring the

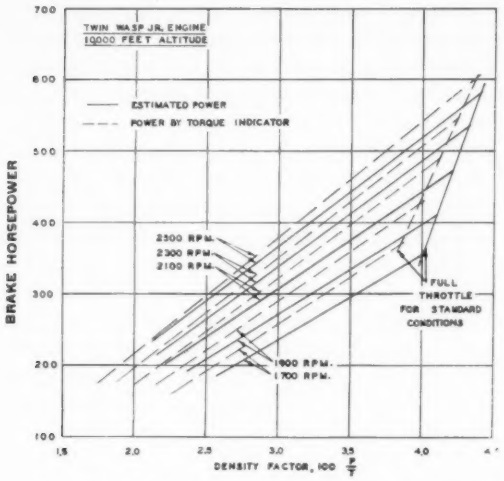


FIG. 8. Comparison of measured and estimated powers on the density-factor basis.

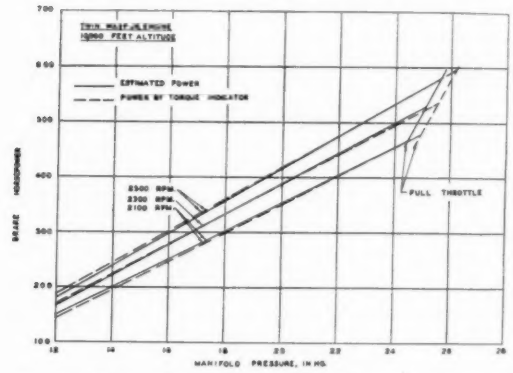


FIG. 9. Comparison of measured and estimated powers on the manifold-pressure basis.

new method, the effect of the change in cooling condition resulting from addition of the cowling should be noted. In Fig. 10, the shift of the mean curve is relatively small, while in Fig. 11 the addition of cowling appears to introduce large errors, particularly at the higher powers. This comparative result is not unexpected in view of the basic nature of the density-factor system. The power estimated from carburetor-air-temperature measurement would be expected to be in error after a serious change in the cooling condition for the intake system. As will appear below, some of the scattering of points in Fig. 10 may be due to variations in mixture strength from that for true best power.

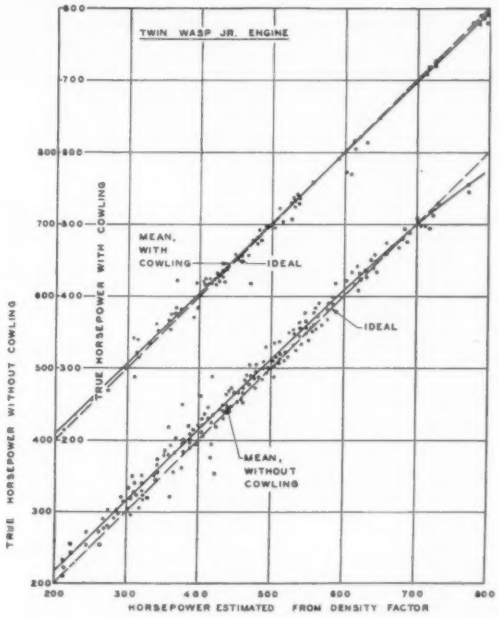


FIG. 10. General comparison of estimated and measured powers using the density-factor method.

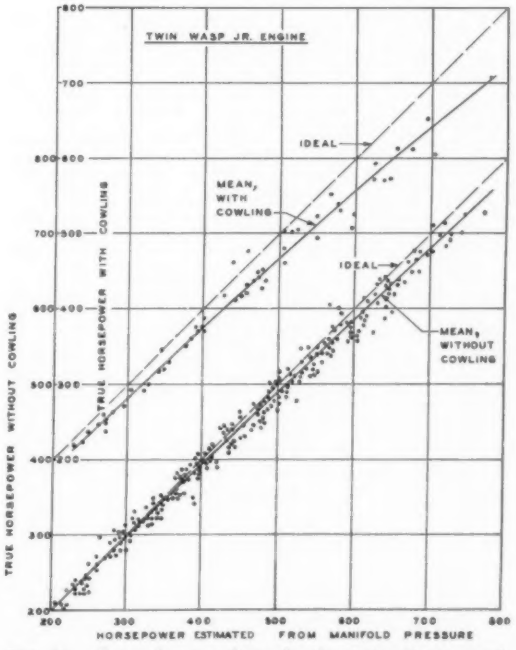


FIG. 11. General comparison of estimated and measured powers using the manifold-pressure method.

LOCATION OF INTAKE THERMOCOUPLE

The question of the best location for the measurement of the density factor has received considerable attention in the flight work. The data presented in Figs. 6 and 10 for the Twin Wasp Jr. engine were based on density factors taken in the intake port, but readings were also made at the blower rim and in the intake pipe just outside of the port. A comparison of the results under various conditions showed that the position in the intake pipe was considerably less satisfactory than that within the port, from the point of view of reducing the apparent change due to the addition of cowling. With measurement at the blower rim the apparent effects of the cowling change were of about the same magnitude as for the intake-port location.

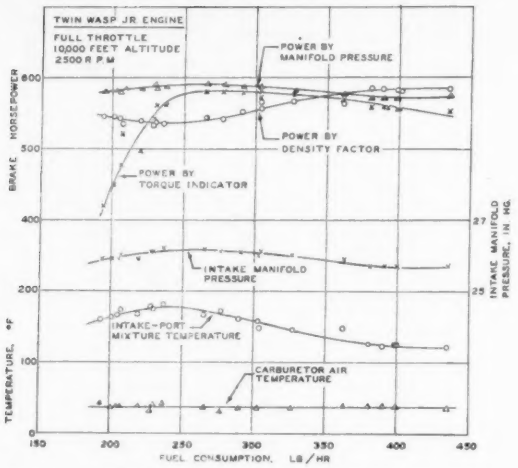


FIG. 12. Effect of mixture strength on power estimation.

From these tests, it appears that either of the extreme positions for the thermocouple should be satisfactory, but other work has indicated that this is not necessarily the case. Dynamometer tests made on a Hornet engine with and without inter-cylinder baffles showed a marked superiority for the intake-port location. A single curve of power at constant speed against density factor was found to fit test points obtained with both cooling conditions when the port temperature was used, but two distinct curves appeared when the density factor was calculated from blower-rim temperature. In other cases it was found that the effects of blow-back on measurements in the port became more serious as the throttling was increased, and indications of a relation between blow-back and exhaust-back pressure could be seen.

It is evident that further systematic work is required to find a definite answer to the question of thermocouple location, as the tests to date have merely indicated that there are factors which may affect the validity of power predictions if a change in installation characteristics is introduced. A more careful study of the question and the adoption of a standard location should go far toward elimination of errors.

EFFECTS OF MIXTURE STRENGTH

Any method for calibrating engines and for estimating engine power in flight is expected to be valid only for the condition of mixture strength at which the calibration was run. In general, such work is done entirely at best power, and no attempt is made to use the power charts for operation under very rich or very lean mixture conditions. In flight work without special instruments, however, accurate setting of the mixture control for best-power operation is difficult, and, as has been shown by tests with the torque indicator, there is a considerable range of fuel-air ratios over which the power is nearly constant. This entire range may be justly considered to be the best-power condition. It is desirable, therefore, for tests where a torque indicator is not used, to employ a method of estimating power that is not sensitive to changes in fuel-air ratio within this best-power range.

Fig 12 shows a sample of the results obtained in a study of this question, where measurements were made with a Twin Wasp Jr. engine at constant altitude and engine speed and at full throttle with various settings of the mixture control. The true power as determined by the torque indicator shows the usual variations from a low output at very lean mixtures up to a comparatively flat peak with a subsequent drop on the rich end of the curve. To compare with this curve, points of power estimated by the two methods from calibrations at best power have been plotted. As is to be expected, the estimated values are seriously in error for the lean end of the curve. Within the best-power range, the manifold-pressure power is nearly constant while the density-factor power appears to show some effects of mixture strength. This change in estimated power results largely from the change in the indicated intake-port temperature shown in the figure. There appear to be two possible explanations for this phenomenon. If liquid fuel is present at the point of temperature measurement in increasing quantities as the fuel consumption is raised, the "wet bulb" effects might increase to give a false low reading. The temperature indication may be considerably affected by the temperature of the cylinder head, and since this is reduced with enriching of the mixture, the effect may be transmitted to the intake-port thermocouple. It appears in any case that a completely reliable indication of the temperature of the mixture has not been obtained under all conditions, or if the temperature measurements are correct, there are other upsetting influences that are not adequately represented.

A similar test was run on a Twin Wasp engine with a torque indicator to obtain the data shown in Fig. 13. In this case the power was held constant by adjustment of the throttle for each change in mixture setting; the variations in the density factor then serve to indicate its inadequacy for power estimation at conditions other than best power. In this case the changes in density factor result mostly from the adjustments of manifold pressure required to hold constant power. Changes in the indicated mixture temperature with mixture strength were of much smaller magnitude than those in Fig. 12; a range of only about ten degrees was found both in the intake port and at the blower rim.

As noted on the figure, the Twin Wasp tests were run with several settings of the flap on the controllable engine cowl to study the influence of cooling on power indications. In this case there appeared to be no consistent effect on the density factor at either location, although the general scattering is perhaps some-

what worse at the blower rim. These results, in comparison with those above for the Twin Wasp Jr. engine, indicate that, while such serious changes as complete removal of the cowl may invalidate the power estimates, normal changes such as may result from cowl adjustment should not cause large errors. This conclusion is important in connection with power prediction from dynamometer calibrations, where the cooling condition and general installation characteristics in the ground test may be markedly different from those in flight.

Comparative Merits of the Two Methods

In a general discussion of the comparative merits of the density-factor and conventional methods, mention should be made of the disadvantage of the density-factor basis as used here which results from the use of measurements on only one out of many cylinders. The manifold-pressure and carburetor-air-temperature method is concerned with the supply of air which ultimately is distributed among all cylinders and might for this reason tend to represent more nearly the average output. This cannot, however, be considered to be a serious drawback for the new method, since the technical difficulties required to obtain an average of the temperatures of the mixture at several cylinders are by no means severe.

There are, of course, other factors which may influence the reliability of any method of estimating engine power, such as the presence of fouled spark plugs or worn engine parts, but there seems to be no hope that loss of power from such causes can be detected by any means other than direct measurement of the crankshaft torque.

As a summary of the general situation regarding power estimation, it appears from the work done thus far that there is but little practical choice between the two methods discussed here. The density-factor method appears to be basically the more sound, but errors are introduced due probably to the difficulties involved in the technique for obtaining accurate temperature measurements in the intake port or intake pipe. In the manifold-pressure method, the measurements to be taken are not subject to quite so many adverse influences, but the basis on which the method is constructed appears to be fundamentally incorrect. The common assumption that the power output at constant manifold pressure is inversely proportional to the square root of absolute carburetor-air temperature can be definitely wrong under certain circumstances. Data are available, for instance, to indicate that the variation in many cases is to more nearly the first power than the square root.

The possibilities of further improvement in the manifold-pressure method seem to be slight, as the variables measured are not closely enough related to those factors which actually govern the engine output. For the newer method, the future seems to depend upon

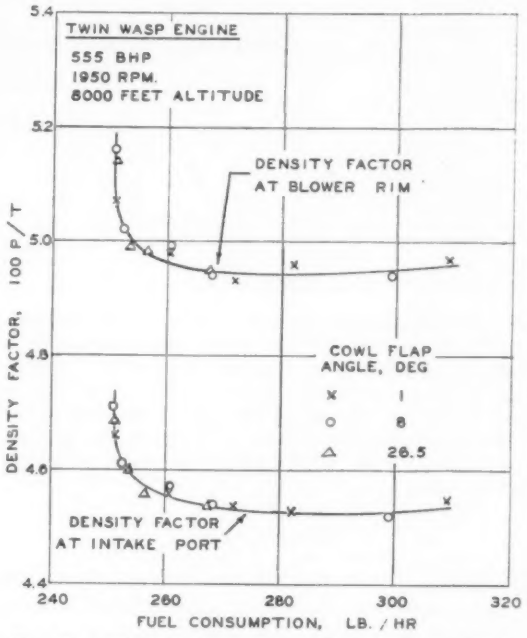


Fig. 13. Effect of mixture strength at constant power with various cooling conditions.

the development of a suitable technique for temperature measurement. This development may need to involve methods for measuring the temperature of the mixture in the intake port free from influences of the hot metal of the cylinder head surrounding it, and with provision to avoid the effects of liquid fuel. Possibly the detail design of thermocouples and shields for them might be improved, although such alterations as have thus far been tried have had but little effect.

In relation to the future possibilities of any method for engine calibration, some mention should be made of the technique required for dynamometer tests on the ground. For example, the engine on test should be equipped with baffles as nearly as possible representing those which will be used in service; anything which can be done to provide airflow conditions around the engine similar to those with a typical installation in flight should be beneficial. The temperatures of the cylinder heads and other parts of the engine should be maintained at values representative of those to be experienced in the air, and even the temperature distribution pattern over each cylinder should be carefully watched.

Further work on this problem should be directed toward duplicating more accurately flight conditions on the ground and toward clearing up the difficulties connected with the temperature measurement problem.

References

[1] MacClain, A. L., and Buck, R. S., *Flight Testing with an Engine Torque Indicator*, S.A.E. Journal, Vol. 42, No. 2, pages 49 to 62, February, 1938.

[2] Gagg, R. F., and Farrar, E. V., *Altitude Performance of Aircraft Engines Equipped with Gear-Driven Superchargers*, S.A.E. Journal, Vol. 34, No. 6, pages 217 to 225, June, 1934.

Monocoque Fuselage Circular Ring Analysis

BENJAMIN F. RUFFNER, JR., *Oregon State College*

(Received November 21, 1938)

Summary

A method of solving for stresses in a uniform circular ring loaded with concentrated loads which are held in equilibrium by the distributed reactions in the fuselage is described. Formulas giving the shear, direct force, and bending moments in a ring loaded with a pair of symmetrically placed concentrated loads are derived. It is indicated how these formulas may be applied to cases where several pairs of symmetrically placed concentrated loads are acting.

Introduction

FORMULAS for the stress analysis of circular rings under a variety of concentrated loadings have been derived[1] for the condition where the ring is held in equilibrium under the action of other concentrated loads. These are well known and have been in common use for some time. In many cases, however, monocoque fuselage circular rings are subjected to concentrated loads which are held in equilibrium under the distributed shear reactions in the fuselage skin. A method has been developed[2] whereby these distributed skin reactions are replaced by a series of concentrated loads and use is made of the formulas given in reference 1. This method is general in its application, but unduly complicated in certain cases where any symmetry of loading is involved.

The method described herein shows how it is possible to derive relatively simple formulas which may be used in solving directly for the bending moments, shears and direct loads in the ring provided the concentrated loads are placed symmetrically about a diameter. This method can also be extended to derive formulas for unsymmetrically placed concentrated loads, but only the symmetrical case is considered here.

Explanation of Method

The basic assumptions made are the same as those made in the derivation of the formulas given in reference 1. These limit the application of the formulas to rings of fairly large diameter as compared to depth. Also it is assumed that the fuselage skin is equally effective in supporting shear loads at all points. This assumption will introduce negligible error in the present analysis since the largest portion of the skin reactions occur on the sides of the fuselage.

Using the notation as shown in Fig. 1, the differential loads on the skin may be represented by the following formulas:[3]

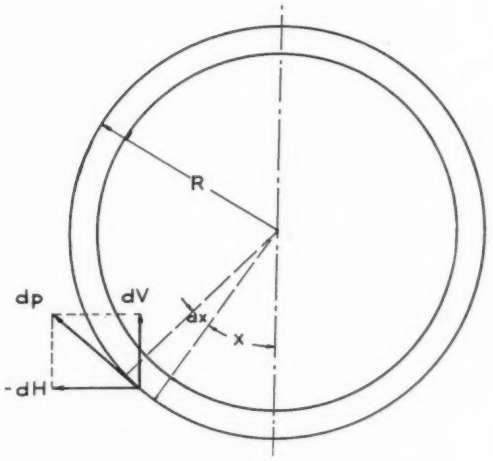


FIG. 1. Notation used for skin reactions.

$$dp = K \sin x dx \tag{1}$$

$$dV = K \sin^2 x dx \tag{2}$$

$$dH = -K \sin x \cos x dx \tag{3}$$

The constant K may be determined from the condition that the sum of the vertical components of the skin reaction must hold in equilibrium the sum of the concentrated loads. This means that $W = 2\int_0^\pi dV$ from which,

$$K = W/\pi \tag{4}$$

In general, the ring is a triply redundant structure. The shear load, the bending moment, and the direct load at some section of the ring must be known before the forces and moments acting on any other section can be computed from the equations of static equilibrium. In the case of symmetrically applied concentrated loads, however, the shear force across the axis of symmetry must be zero. This ring then becomes a doubly redundant structure.

Fig. 2 shows a loading which is commonly found on monocoque rings. If a typical element in the interval from $x = 0$ to $x = \theta$ is considered, the forces and moments are as shown in Fig. 3. The moment M_{x_1} and the forces P_{x_1} and S_{x_1} may be then written in terms of the unknown values M_0 and P_0 as follows:

$$S_{x_1} = K\left[\frac{\sin^3 x_1}{2} - \cos x_1\left(\frac{x_1}{2} - \frac{1}{4}\sin 2x_1\right)\right] - P_0 \sin x_1 \tag{5}$$

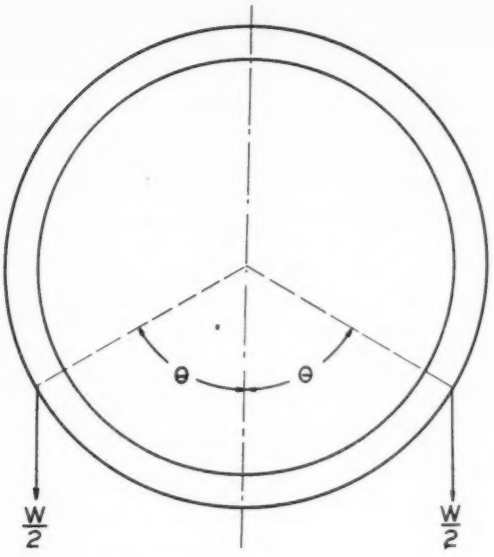


FIG. 2. Location of concentrated loads.

$$P_{x_1} = P_0 \cos x_1 - (K/2)x_1 \sin x_1 \quad (6)$$

$$M_{x_1} = M_0 + R(P_0 - K)(1 - \cos x_1) + (KR/2)x_1 \sin x_1 \quad (7)$$

If a typical element in the interval from $x = \theta$ to $x = \pi$ is considered, the following expressions are obtained:

$$S_{x_2} = -K\left[\frac{\sin^3 x_2}{2} - \cos x_2\left(\frac{x_2}{2} - \frac{1}{4}\sin 2x_2\right)\right] - P_0 \sin x_2 + \frac{W}{2}\cos x_2 \quad (8)$$

$$P_{x_2} = P_0 \cos x_2 - \frac{K}{2}x_2 \sin x_2 + \frac{W}{2}\sin x_2 \quad (9)$$

$$M_{x_2} = M_0 + R(P_0 - K)(1 - \cos x_2) + \frac{KR}{2}x_2 \sin x_2 - \frac{WR}{2}(\sin x_2 - \sin \theta) \quad (10)$$

The total strain energy U in the ring due to bending is

$$U = 2\int_0^\theta \frac{M_{x_1}^2 dS}{2EI} + 2\int_\theta^\pi \frac{M_{x_2}^2 dS}{2EI}$$

The principle of least work states that $\partial U/\partial M_0 = 0$, and $\partial U/\partial P_0 = 0$. These conditions give

$$\int^\theta M_{x_1}\frac{\partial M_{x_1}}{\partial M_0}dx + \int_\theta^\pi M_{x_2}\frac{\partial M_{x_2}}{\partial M_0}dx = 0 \quad (11)$$

$$\int_0^\theta M_{x_1}\frac{\partial M_{x_1}}{\partial P_0}dx + \int_\theta^\pi M_{x_2}\frac{\partial M_{x_2}}{\partial P_0}dx = 0 \quad (12)$$

These equations give two expressions involving P_0 and M_0, which when solved simultaneously give

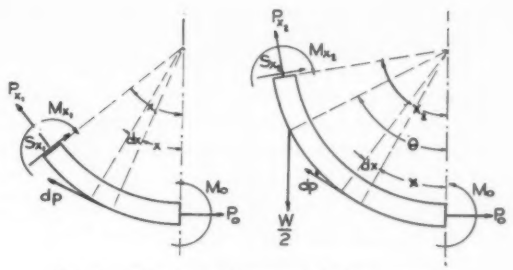
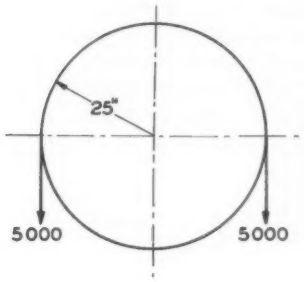


FIG. 3. Free body diagrams of ring elements.



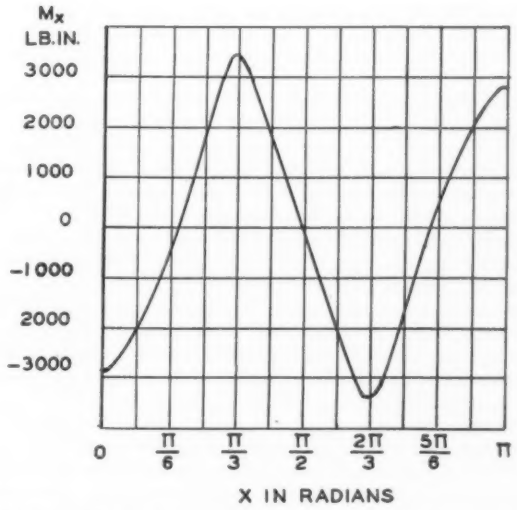


FIG. 4. Loading and bending moments for ring used in example.

$$P_0 = (W/2\pi)(3/2 - \sin^2\theta) \quad (13)$$

$$M_0 = -(WR/2\pi)[(\pi - \theta)\sin\theta - \sin^2\theta - \cos\theta] + WR/4\pi \quad (14)$$

EXAMPLE

The use of these equations is best shown by a concrete example. Consider the ring loaded as shown in Fig. 4. From Eq. (4), $K = W/\pi = 10000/\pi = 3183$. For this particular case $\theta = \pi/2$, so from Eq. (13), $P_0 = 10000/4\pi = 795.8$, and from Eq. (14), $M_0 = -2817$. Eqs. (7) and (10) then become

$$M_{x_1} = -2817 - 59680(1 - \cos x_1) + 39788x_1 \sin x_1 \quad (15)$$

$$M_{x_2} = -2817 - 59680(1 - \cos x_2) + 39788x_2 \sin x_2 - 125000 (\sin x_2 - 1) \quad (16)$$

If values of x are substituted in these equations the bending moments on the ring may be computed. The results of these calculations are shown on Fig. 4. These values check very well with the results as given in reference 2 obtained by the method of splitting the skin reactions into a series of concentrated loads.

Conclusions

These formulas may be easily extended to cover cases where several symmetrical pairs of concentrated loads are acting simultaneously. The forces and moments can be computed for one symmetrical pair at a time and the resulting values added at corresponding points.

When applying these formulas calculations should be carried out to about five significant figures. This is necessary because small differences between large numbers arise in some problems.

It is recommended that R be taken as the outer radius of the ring rather than the radius to the centroidal axis of the ring. This will give conservative values for the moments.

References

[1] Miller, Roy A., and Wood, Karl D., *Formulas for the Stress Analysis of Circular Rings in a Monocoque Fuselage*, N.A.C.A. Technical Note 452.

[2] Greenwood, Ernest J. A., Jr., *A Method of Stress Analysis of Monocoque Fuselage Rings*, Journal of the Aeronautical Sciences, Vol. 3, No. 12, page 440, October, 1936.

[3] Younger, J. E., *Structural Design of Metal Airplanes*, McGraw-Hill, page 226.

Book Reviews

The Story of the Winged-S, by Igor I. Sikorsky; Dodd, Mead and Company, New York, 1938; 266 pages, $3.00.

The modesty and reticence which have been outstanding characteristics of the private life of Igor Sikorsky have veiled the earlier part of his career so completely that while it was well known that he designed and built multi-engined aircraft in Russia during the War, the full significance of the preparatory work has never been properly appreciated.

To most of his friends he has been regarded as a cultured and educated engineer refugee who gathered around him others similarly situated, and by sheer hard work and technical skill, surmounted difficulty after difficulty until he found recognition for his achievements.

But his autobiography gives a much closer view of this great aeronautical pioneer and reveals the driving force which has sustained him through many trials. The book should take its place as one of the masterpieces of aeronautical literature. Its literary excellence, while not surprising to those who know the author, has a clarity and style which hold the reader's interest to the last chapter. As an historical document covering the early days of aviation in Europe, it gives an intimate record of the struggles of the pioneers. It introduces to the reader a Russian family of the Ukraine whose head was a distinguished psychologist and physician. The element of sacrifice which has been so important in the lives of many successful aeronautical engineers is emphasized in the early chapters.

The Sikorsky saga divides itself clearly into two parts and the book follows this pattern. The first half is devoted to the struggles of the Russian youth to acquire a technical education in his home city of Kiev. Because of his interest in building and flying experimental planes, he had little time left to devote to formal education.

Fortunately, the father and sister of Igor were willing to risk their funds, enabling him to go to Paris and study existing aircraft. He returned with an Anzani three-cylinder engine around which he tried to develop a helicopter. After two unsuccessful attempts, he abandoned this type and turned to the more conventional design of flying machine. Success attended his efforts, and within the space of a few years, the name Sikorsky became identified all over the world with four-engined cabin airplanes, carrying up to sixteen passengers. During the war he built and delivered to the Front, seventy-five such planes.

Because he was out of sympathy with the Marxist ideals, he left Russia shortly after the beginning of the Revolution. With commendable forbearance he omits from his book any ill tempered comment on his reasons for leaving success, fortune, and family behind, and, with a few hundred dollars, beginning a new career abroad. After a short time in Paris he came as an immigrant to New York.

No one can read of the struggles of this small group of emigrées to establish themselves in the new economic life of this country without admiration for their courage, persistence, and sacrifices. Under the leadership of Sikorsky, they organized a company to build airplanes. Several disappointments followed, but the airplanes that were built had fundamental characteristics that reflected the skill of an experienced designer, and each succeeding type brought more substantial support. Out of this extraordinary background came the great Sikorsky series of flying boats and amphibians that have brought world wide fame to their designer.

The insipiration for his work and the thread which runs through the book is his belief in large aircraft. With the requirements of the Pan American Airways for larger and more efficient flying boats, the types from 38 to 43 were developed, and successfully pioneered the great network of our international air line.

The closing chapters deal with the future possibilities of larger air transports, particularly for transoceanic service. Here, again, he displays his confidence in the efficiency of still larger aircraft.

The book will be an inspiration to young men who see only discouragement ahead. It shows how success is achieved by following a chosen path uninfluenced by failure or discouragement.

The Story of the Winged-S deserves its place as one of the "must" books of aeronautics.

Lester D. Gardner

This Flying Game, by MAJOR GENERAL H. H. ARNOLD and LIEUT. COL. IRA C. EAKER; Funk and Wagnalls Company, New York, 1938; 300 pages, $3.00.

The great advances in aviation since the first edition of this book appeared in 1936 made a new and up-to-date edition advisable. Since that time, General Arnold has been made Chief of the Air Corps. Two new chapters, "Aviation of Recent Date" and "Lessons from Current Air Wars," have been added. The former is an account of progress made by military, naval, and technical aviation and a record of recent spectacular flights. The latter is a genuine contribution, coming as it does from officers who have access to much information not available to the general public.

In the study of the use of the airplane in the Spanish War, it is pointed out that this war is a very loosely integrated civil conflict. The air experience on both sides has been limited and only indications can be obtained. However, some important conclusions can be drawn. The most important is that nations will need their air forces before the beginning of the conflict in order to carry on successful air warfare at the outbreak of hostilities. Preparations will have to be made for two distinct types of operations: air cooperation missions and air force missions, and airplanes must be designed and equipped for the task they are expected to perform. An air force must be more than a collection of miscellaneous airplanes. The powers, capabilities, and limitations of bombardment aircraft have not been properly tested in Spain. The discussion of these points makes this chapter of great value to students of current events.

The authors believe that the war in China demonstrates what a well organized and equipped air force can do against a group of miscellaneous aircraft, even through the latter may be flown by daring pilots. The destruction of strategic rail heads, factories, and the burning of the inflammable houses are illustrations of what may happen to countries whose air defense is inadequate at the beginning of the hostilities.

The discussion of the latest developments in the field of air defense, both passive and active, is excellent. Instead of belittling this form of defense, it is evaluated from a realistic viewpoint. The lack of mobility is stressed, but the advances made are fully appreciated.

The trend of the year 1938 is aptly named "The World Armament Race." The great production of airplanes in Germany, Italy, and England is reviewed and the progress made in the United States in various aeronautical fields is given due credit.

The new edition is a worthy effort and will contribute to a better understanding of what can be expected of aviation in the future.

Early Birds, by ALFRED INSTONE; Western Mail and Echo, Ltd., Cardiff and London, 1938; 196 pages, 6s.

The title of this book would suggest to American readers that it deals with pilots who flew before the War. Instead there is little about pilots, other than Captain F. L. Barnard, the first pilot of the Instone Air Line, the history of which comprises the subject matter of the book.

Historians will find in this book excellent source material on the beginnings of British air transport. Sir Samuel Instone and his two brothers, who were engaged in the coal and shipping business, believed that they could expedite their manifests by using airplanes. Out of this idea the Instone Air Line grew. It was one of the four to be organized after the war to carry mail, express, and passengers from London to the Continent. They were finally merged into the Imperial Airways.

This book is more than a history of one company. It gives the problems encountered by all air transport operation in this early period, and, particularly, gives the reasons for the introduction of subsidies. In the truest sense, the Instone brothers were pioneers in the development of air transport and deserve great credit for their contribution.

The World Was My Garden, by DAVID FAIRCHILD; Charles Scribner's Sons, New York, 1938; 418 pages, $3.75.

Sometimes there is to be found in books that are not primarily concerned with aviation, chapters which are real contributions to aeronautical knowledge—particularly historical.

Dr. Fairchild is a world famous botanist whose career included travel in many lands. The book is really an autobiographical account of these travels.

He married the daughter of Alexander Graham Bell and was present at Baddeck and Hammondsport during the early experimental period of aviation. He knew Octave Chanute, Glen Curtiss, Dr. Langley, Lt. Selfridge, and Douglas McCurdy. Two chapters of the book give his recollections of the early work of these pioneers. He saw the first flight of Curtiss at Hammondsport and also the first flight of Orville Wright at Fort Meyer.

He writes of these experiments with first hand knowledge and provides those who are interested in the beginnings of aviation in this country an eye witness account that will be useful to future historians.

Sky Roaming Above Two Continents, by HARRY A. FRANCK; Frederick A. Stokes Company, New York, 1938; 362 pages, $3.50.

This book represents the author's twenty-second travel narrative, and one rightly expects to find in it the impressions of an experienced observer. In his trip to the Canal Zone via Mexico and back via Venezuela and the Caribbean Islands, Mr. Franck has not only observed keenly, but has added many recollections of previous visits when transportation was more primitive.

The author's description of air travel has a freshness and enthusiasm for those features which the seasoned air traveler takes more or less for granted. For that reason, this part of the book will probably be of more interest to the general reader than seemingly more informed comment would be.

The book is more than a guide book, although the detailed information given would recommend it for that purpose. The reader will be more and more impressed with successive chapters by the detailed observations of the customs, habits, and character of the people who live in the countries to the south of the United States. Almost invariably Mr. Franck seeks out the people who make up the bulk of the population, those in the poorer districts of the cities and those in the rural areas, rather than limiting his observations to the higher classes, as so many writers do. This feature enhances the value of the book and makes it a helpful aid in understanding the characteristics of the various peoples.

The visitor to Central and South America is at a decided advantage if he can speak both Spanish and French fluently. It permits exploring the minds as well as the habits and customs of the people.

In a little over two months, Mr. Franck landed at fifty-six places and made twenty-seven stopovers. At each stop he apparently spent every minute collecting information for his book. His vast experience in writing travel books enabled him to acquire the information in a minimum of time. The book will be interesting to those who wish to learn about the people in Central America and it will be especially valuable to those who are planning a trip around the Caribbean countries and islands by Pan American Airways.

The aeronautical specialist will be impressed by the great value of the airplane in these countries where other forms of transportation are still quite primitive.

Institute Notes

Annual Meeting—1939

Honors Night Dinner

The Annual Meeting of the Institute will be held on January 25, 26, and 27, 1939, at Columbia University, New York City. Copies of the papers to be presented are not available through the Institute; requests for these should be directed to the respective authors.

The Honors Night Dinner will be held on Friday, January 27, at the Biltmore Hotel. At the dinner the Sylvanus Albert Reed Award, and the Lawrence Sperry Award will be presented. The newly elected Fellows of the Institute will be given their certificates and the next President of the Institute will be inaugurated.

Branches

In commemoration of the thirty-fifth anniversary of the first flights of the Wright brothers at Kitty Hawk, the Second Wright Brothers Lecture was held in New York at Columbia University on the afternoon of December 17. At this meeting, Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division of the National Bureau of Standards, delivered the lecture, which had as its subject "Turbulence and the Boundary Layer." The lecture and the discussion following it are printed in full in this issue.

Simultaneously with Dr. Dryden's presentation of the lecture in New York, over 25 Branches of the Institute throughout the country held meetings, at which Dr. Dryden's lecture was repeated by a speaker selected by the Branch.

While reports have not been received from all of the Branches, many of them have indicated that very successful meetings were held.

At the University of Cincinnati, Corrie C. Cammack opened the meeting with an account of the work of the Wright brothers, after which Professor H. W. Sibert presented the lecture before the Student Branch. Professor R. H. Mills of the Georgia School of Technology presented the lecture at that school, and Edward Miller, of the Polytechnic Institute of Brooklyn, presented the lecture before members and guests of the Polytechnic Student Branch.

At the University of Michigan, Professor M. J. Thompson opened the meeting with a short talk on the history and significance of the work of the Wright brothers, and Ralph Upson read the lecture to over one hundred members and guests. Following the lecture there was an informal discussion of boundary layer theory and its engineering applications.

The San Francisco Branch of the Institute held a formal organization meeting preceding the lecture, at which John C. Leslie was elected as Chairman, Dr. Norton B. Moore, Vice-Chairman; and Walter F. McGinty as Recorder-Treasurer. Following the organization meeting, the lecture was read by Dr. Norton B. Moore to an audience of students and faculty members of the University of California and engineers from schools and companies in the vicinity.

A meeting of the Tri-State College Student Branch of the Institute was held on December 1 at which the following officers were elected: Arthur Mallory, Chairman; E. E. Cleveland, Vice-Chairman; W. S. Warner, Secretary-Treasurer. A second meeting was held on the occasion of the Wright Brothers Lecture, at which L. D. Ely, Honorary Chairman of the Student Branch, presented the lecture.

Code of Ethics

After careful consideration during the past year by the Council and the Advisory Board, a Code of Ethics has been tentatively adopted for the guidance of the members of the Institute. The Council has authorized publication of this Code in order that all members of the Institute may study it and have the opportunity to make suggestions. Most of the engineering societies have adopted codes which give those entering their field a statement of the standards of the profession. Before taking final action the Council will wait six months.

Proposed Code of Ethics

Institute of the Aeronautical Sciences

It is assumed that a member is a person in whom qualities of high character are inherent, such as, patriotism, integrity, devotion to high ideals of personal honor and of professional service and honesty, a broad spirit of fairness to all concerned, and that these qualities fundamentally control all his judgments and decisions. There are, however, many marginal matters of professional conduct about which men of highest character may wish a clear statement. The I. Ae. S. has, therefore, adopted the following Code of Ethics:

1. A member of the I. Ae. S. will advertise only in a dignified manner. Professional advertising should be limited to factual information regarding the advertiser's experience and the nature of the work that he is prepared to undertake. It should include no general claims of superior merit, and no specific citations of past professional engagements of a consulting nature except with the specific permission of the clients concerned. He will make no use in advertising of the fact of his membership in the Institute, or of the grade of such membership. "Advertising," in this sense, does not refer to the use of the accepted abbreviations for Institute membership following the name on the business letterhead or in any publication of biographical data for which no payment is made.

2. He will not allow himself to be associated with any attempt to suppress information bearing vitally upon the safety of a structure or of its operation.

3. He will not allow himself, either by affirmative claim or by passive acceptance, to receive credit for the work of others.

4. He will not approve, and as far as possible he will prevent, any use of his name or any quotation of his views in a form or context liable to create a misleading impression regarding the actual nature of his connection with an enterprise, the scope of an investigation that he has made, or the conclusions that he has reached.

5. He will not express his formal opinion in the absence of what he regards as an entirely adequate investigation, without making plain the limitations to which the inquiry was subject. He will not serve in any capacity where he must pass upon or approve of his own work.

6. He will not accept any type of professional relationship or form of compensation for professional service which might be expected to bias his judgment. He will not, for example, undertake to make a report upon the merit of a project in return for a fee the amount of which is contingent upon whether or not a decision is taken to pursue the project.

7. He will accept compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.

8. He will inform a client or employer of any present or past business connections, patent interests, personal relationships, or other affiliations which might influence his judgment or impair the disinterested quality of his service.

9. He will regard as permanently confidential any information obtained by him as to the business affairs and technical methods or processes of a client or employer. He will also hold as permanently confidential, information not common knowledge or public property, which is obtained in connection with professional employment, and will not transmit it to any other party in any fashion that could injure the interests of the client or employer in connection with whose work the information was first received.

Personnel Opportunities

The Personnel Bureau serves organizations seeking to employ aeronautical specialists as well as individual members. Any member or organization may have requirements listed without charge.

Available

Graduate in Aeronautical Engineering with 4 years' experience in aeronautics in the capacity of draftsman and designer is seeking a connection in the west. Reply Box 78, Institute of the Aeronautical Sciences.

Wanted

Persons qualified to instruct in subjects of airplane design, aerodynamics, airplane structures, and wind tunnel. Reply Box 79, Institute of the Aeronautical Sciences.

Wanted

Aeronautical Engineer capable of supervising and directing men in originating and designing all-metal airplanes conforming to Army and Navy requirements. Reply Box 80, Institute of the Aeronautical Sciences.

Wanted

Structural Engineer with recent design experience on all-metal airplane structures for Army and Navy. Reply Box 80, Institute of the Aeronautical Sciences.

Wanted

Fixed equipment, Power Plant and Armament Layout men and designers with experience on recent Army and Navy airplanes. Reply Box 80, Institute of the Aeronautical Sciences.

Necrology

CHARLES B. BUERGER

Charles B. Buerger, an Associate Fellow of the Institute, died on January 3, 1939, at the age of 57.

Mr. Buerger had been Vice-President in charge of manufacturing of the Gulf Oil Corporation since 1929, having served as General Manager for several years prior to that time. Before becoming associated with the Gulf Corporation he served as General Manager of the New England Oil Refining Company. He held several patents on oil refining equipment and was considered an authority on the building and operation of refineries.

He was a member of the A.S.C.E., the A.S.M.E., the Society of Naval Architects and Marine Engineers, and the Institute of Petroleum Technologists, and was a member of the refining committee of the American Petroleum Institute. He served on the five man board of review of the N.R.A. planning and coordination committee.

Mr. Buerger was born in Vienna, Austria, and came to this country as a boy. He attended the College of the City of New York, graduating with a B.S. degree. He received a M.E. degree from the Stevens Institute of Technology.

Letter to the Editor

Dear Sir:

My article entitled "Pressure Waves Accompanying Detonation in the Internal Combustion Engine" which appeared in the April, 1938 issue of the Journal, contained certain errors. These errors do not change the conclusions given in the paper but would cause inconvenience to any person wishing to use the data as given for studies of detonation waves.

The curves and the table have been recalculated. The results have been incorporated in figures to replace the figures given in the article. Corrected reprints and photostated copies of the curves have already been sent to several organizations known to be working on detonation. A limited number of additional copies are available to interested parties if they will communicate with me directly.

C. S. DRAPER
Massachusetts Institute of Technology

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Practical Method of Determination of Pressures on the Profile of an Empirical Wing. H. Girerd and L. Servanty. Simple method for tracing the curve of pressure distributions on any empirical profile. Operations are given for determining the correspondence of points of any profile on those of a circle in the conforming transformation which makes the area exterior to the profile correspond to the area exterior to the circle, without deformation or displacement of surfaces to infinity. Potential function is defined on the profile for each incidence, and the local velocity at each point is obtained by methods utilized for theoretical profiles.

Diagrams illustrate variation of pressure on a point of the Clark Y profile in function of the total lift (agreeing with experimental values obtained in the N.A.C.A. variable-density wind tunnel for Reynolds Numbers around 0.356×10^6 and 6.700×10^6) and calculated pressures on the Clark Y profile, calculations also being given. *L'Aéronautique, L'Aérotechnique Supplement*, October, 1938, pages 125–133, 6 illus., 2 tables, many equations.

How to Construct a Great Many Types of Plotters for Joukowsky Profiles. P. Léglise. Number of mechanisms are described which were designed for outlining Joukowsky profiles, including a hundred new types of plotters for "homothetic 1/2" profiles and a great many more new types of plotters for direct Joukowsky profiles. *L'Aéronautique, L'Aérotechnique Supplement* October, 1938, pages 133–140, 11 illus.

The New Fairey Research Laboratories. Fairey closed return-circuit wind tunnel has a closed working section of elliptical shape 12 × 10 ft. and a circular-section circuit of 22-ft. maximum diameter and covering a space 110 ft. long and 50 ft. wide. Maximum speed of the airstream in the working section is more than 145 m.p.h. and a Reynolds Number of about 2,000,000 (2×10^6) can be attained for a model 18 in. long. Five radial straightener vanes in front of the propeller and five in back straighten out the airstream.

Description of wind tunnel, as well as of the equipment of the structures and metallurgical sections of the Department. *Aeroplane*, Nov. 2, 1938, pages 531–533, 7 illus.

Few details of wind tunnel and reference to the Fairey v.p. propeller hub, said to have a simple and ingenious operating mechanism and to be destined to be used extensively. Hydraulically-controlled full-feathering propellers were undergoing mechanical tests. *Flight*, October 27, 1938, page 362, 2 illus.

The National Physical Laboratory—Aerodynamics Department. Effects on minimum profile drag and maximum lift of the rivet heads and lapped joints on wing surfaces up to a Reynolds Number of 8×10^6 were investigated by means of a model wing mounted in the compressed-air tunnel. Research on effect of laminar flow over the entire wing surface is being carried out in the same wind tunnel on a model fitted with pressure holes for exploring pressure distribution. Open-ended pitot tubes are traversed over the span close to the surface.

Discussion covers this research, as well as drag tests on seaplane hulls and on streamline bodies of various slenderness ratios, application of the pitot-traverse technique to measurement of drag of wings at speeds approaching those of sound, and stability research. Destabilizing moment of engine nacelles turned out to be much greater than appreciated and tail surfaces are too small or c.g. of the monoplane too far to the rear for adequate stability in flight. Other studies of longitudinal and lateral stability of the monoplane and aircraft control undertaken or planned are described, as well as a device used for stability investigations on kite balloons. *Engineering*, November 4, 1938, pages 526–528, 2 illus.

Introduction to a Series of Reports on Results of the Prandtl Wing Theory. H. Schmidt. Numerical results of the Prandtl wing theory are made available in a series of articles in a form suitable for immediate practical application. This article is an introduction to the eight articles abstracted below and includes an explanation of the symbols used. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 219–222, 4 equations.

Synopsis of the Theory of the "Linear" Wing. H. Schmidt. Starting with generalizations on factors and relationships entailed in the Prandtl wing theory, report defines the main problem of the theory, which is to determine a function denoting distribution of lift in a predetermined wing, which must comply with three clearly defined conditions (for which equations are given). Two methods have been adopted, one leading to the Prandtl integro-differential equation and the other to a limit-value equation, discovered by Trefftz, or to the third limit-value problem of the potential theory of the unit circle. Latter theory shows that there is a definite distribution of lift for all technically correct cases, which is uniform along the whole length of the "linear wing" (Prandtl treated his wing as if it were a single line) and which can be developed to a convergent Fourrier series. Data are given concerning the Fourrier coefficients. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 223–227, 2 illus., 44 equations.

General Opinions on the Preparation of the Numerical Results of the Theory of the "Linear" Wing. A. Kupper and H. Schmidt. Fundamental distributions of the angle-of-attack curve and its standard for zero lift distribution; analogy between two-dimensional tail-surface problems and theory of the linear wing; and remarks on the presentation of numerical results. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 228–231, 1 illus., 17 equations.

Theory of the Lift Distribution of Any Warped Elliptical Wing. H. Schmidt. Third limit-value problem mentioned in the first report, when applied to an elliptic wing, can be reduced to the first limit-value problem, the solution of which can be found with linear differential equations using the potential function already found. A surprisingly simple expression is found for the lift distribution. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 232–234, 4 illus., 24 equations.

Some Characteristics of Elliptical and Non-Elliptical Wings. H. Schubert. Lift distribution of any non-elliptical wing entailing sections with uniform angle of attack can always be expressed as the sum of the lift distribution of an elliptic wing of the same span and with the same variations of angle of attack plus lift distribution of the same non-elliptical wing with uniform arrangement of the angle of attack. Lift distribution and consequent arrangement of induced angle of attack of a non-elliptic wing (in sections of which angle of attack is uniform) are shown to be similar to the same factors in an elliptic wing of the same span and with same arrangement of angle of attack. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 235–242, 72 equations.

Aerodynamic Values of Elliptical Wings. K. Bausch. Mathematica deductions of values for the characteristic features of elliptic wings (total lift and moment of roll, induced resistance, induced torque). D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 243–245, 19 equations.

Calculations for Determining Lift Distribution on Elliptical Wings (Non-Fractional Values of Parameters). H. Schmidt. Lift distribution of an elliptical wing is calculated, non-fractional values of the parameter only being utilized. Equations are given for a general result and also for constant angles of attack and those with linear variations. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 246–255, 51 equations.

Calculations for Determining Lift Distribution on Elliptical Wings (Fractional Values of the Parameter). H. Soehngen. Calculations in the previous section are extended to cover any rational value of certain partial integrals dealt with in the foregoing report. Final result is an equation showing lift distribution. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 256–259, 20 equations.

Numerical Results for Elliptic Wings with Partly Constant and Partly Linear Variation of Angle of Attack. K. Bausch. Numerical results for a special class of elliptic wings with partly constant and partly linear distribution of angle of attack. Results of all cases dealt with are given in schedule form. D.V.L. report. *Luftfahrtforschung*, May 6, 1938, pages 260–274, 16 illus., 18 tables, 12 equations.

The National Physical Laboratory. Investigations of fluid motion, turbulence, atmospheric gusts, airfoils in cascade, wind pressure on bridges, propellers, autogiro blades, flutter, and buffeting are described in detail. Research in the Aerodynamics Department. Research in the Physics Department on international temperature scale, temperature of liquid steel, and furnace control is also discussed. *Engineering*, November 11, 1938, pages 550–553, 1 illus.

The New Transformed Wing Sections. N. A. V. Piercy, R. W. Piper, and L. G. Whitehead. Method of evolving conformal sections of practical utility. Method is the result of research undertaken to find a direct way of producing transformed shapes which, judged from inspection, would rival those recommended by experience, of arranging for adjustment of shape (without losing advantages of conformal transformation) to meet special aerodynamic or structural needs, and of effecting some return to analytical convenience. Symmetric shapes, circularly cambered airfoils of two families, velocity and incidence, velocity surface and field, and pitching moments are discussed in great detail. *Aircraft Engineering*, November, 1938, pages 339–343, 11 illus., 25 equations.

The Original Wind Tunnel of the Wright Brothers. G. Brewer. The Wright Brothers were the first to make a wind tunnel in which miniature wings could be accurately tested, the first to take useful measurements of the lift and drag and travel of the center of pressure on curved surfaces, and the first to compile tables from which an airplane could be designed which would fly. Description of tunnel and research undertaken. *U.S. Air Services*, November, 1938, pages 17–18.

Results and Problems of Aerodynamics. New aerodynamic problems which will arise as the result of new supersonic airplane speeds and new airplane designs. Subsonic and supersonic ranges are considered and flow with the velocity of sound is discussed. *Luftwissen*, October, 1938, pages 353–356, 2 illus.

Aircraft Design

Cooperation of Design and Construction. E. Ritter. Design and construction precautions to be followed in the cooperation of the aircraft design and construction departments. Points considered include: unfinished and semi-finished materials; separate parts and parts production; wing unit structure; final assembly; maintenance and servicing; organization required for cooperation; the human factor in cooperation; and training and experience. *Luftwissen*, September, 1938, pages 311–319, 12 illus.

Double Flaps and Slots on Test. F. Piatelli. Double-slotted flaps on the Piaggio P.32 bomber consist of a Handley-Page slot along the leading edge, a slotted flap at about 60 percent of the chord from the leading edge and a second slotted flap at 80 percent. Flaps are mechanically interconnected, so that the hindermost is always depressed at twice the angle of the other. Results of experimental tests on models of these flaps and wings, shown in graphs, indicate lift can be increased by 2.64 times by using double-slotted flaps and leading-edge slots.

Editor compares these results with values given by Heinkel for the Fowler flap (from article abstracted below) with the wing of the Lockheed 14, and with the Pegna wing. Photograph shows double-slotted flaps along the trailing edge of the Piaggio Procellaria. Abstract and curves are taken from a lecture by F. Piatelli before the Associazione Italiana di Aerotecnica. "Wings and Control Surfaces" presented by D. L. Ellis before the Royal Aeronautical Society is discussed in a subsequent short note. *Aeroplane*, November 2, 1938, pages 528–530, 10 illus.

The Increase in Aeroplane Speed during the Last Few Years. Ernst Heinkel. Technical steps which made possible the performance of the Heinkel He 112-U single-seater fighter now in production for the German Air Force. Standard version (no doubt with a boosted engine) piloted by General Udet, recently did 394 m.p.h. round a closed circuit of 100 km. Increase in airplane performance, with particular reference to speed, is reviewed as indicating expectations for development in the immediate future. Importance of improvements in the design of airplanes, engines, and propellers which made this possible are pointed out.

Means which have led to the present airplane speed of 425 m.p.h. and what should be done to increase this speed to about 560 m.p.h. are discussed in detail, including: removal of all parasitic bodies, reduction of frontal area, improving shape of main units, reducing frictional drag, and adjusting shape to conform to compressibility requirements. One graph shows loss of speed caused by gun mounting, and another the drag for a wing (untwisted) of a single-seater fighter indicating optimum flying height and how speed of sound decreases with height. *Aeroplane*, October 26, 1938, pages 502–507, 18 illus.

Pity the Poor Designer. Organization and working of the complicated machinery which produces aircraft for the R.A.F., and difficulties which arise. Discussion covers: problems which confront the designer when he

starts to plan an aircraft to an Air Ministry specification; "mockup" conferences with Air Ministry experts; stressing; the low-wing cult; interrelationship of the aerodynamic and structural design; and cooling for the engine. Photographs of tail turret and other parts included. *Flight*, October 27, 1938, pages 352–354, 365, 8 illus.

Sitting on the Slipstream. By covering the greater part of the wing with slipstream, and by tilting the propeller axis downward, R. J. Goodman-Crouch and H. Bolas found that a very great increase in lift is obtainable at low forward speeds. Test results and calculations are said to show the Crouch-Bolas scheme will decrease time and distance of take-off by 50 percent, increase angle of climb for same rate by nearly 100 percent, increase speed range by approximately 75 percent, decrease sinking speed to approximately 50 percent of that obtained on modern aircraft fitted with wing flaps, and decrease landing speed and distance run by about 50 percent.

Surprising results obtained in tests carried out in America by these two Englishmen in the wind tunnel, and from actual flying tests with a "somewhat quaint" experimental biplane are discussed. Design of the Crouch-Bolas Speed-Ranger four-engined monoplane (inboard engines each developing 420 hp. and outboard engines, located near the tips, 145 hp.) is described. *Flight*, August 4, 1938, pages 103–104, 9 illus.

Trend in Design of Large Flying Boats. I. I. Sikorsky. Luxurious airliner of 100 tons, powered with 12,000 hp. and having 50 staterooms, luxurious dining room, and cruising speed between 300 and 400 km./hr., according to altitude, is an engineering possibility of the immediate future.

Discussion covers: major factors determining design characteristics of a modern medium-size airplane weighing about 10 tons gross; reasons why parasite resistance of the flying boat will be substantially in excess of the drag of the landplane; influence of size on relative efficiency of landplanes and flying boats, based on a study of planes already built and completed preliminary designs of the author's company; anticipated performances of flying boat and two landplanes of similar power and useful load; characteristics of a 100-ton long-range transport flying boat; influence of size on flying boat only, based on design characteristics of the S-42 and S-43 flying boats; trends in efficiency of the design elements with respect to structural weight and parasite resistance; major design problems of the flying boat; and value of consecutive designs. Lilillienthal Gesellschaft paper. *Aero Digest*, November, 1938, pages 44–47, 76, 84, 5 illus., 3 tables.

Do Remedies for Stalling Exist and Can the Flat Spin Be Avoided? L. Claude. Designer of a "canard" airplane considers that the ailerons of an airplane are great defects because they reverse their effect just at the moment when it is not necessary. Positions of center of pressure and the polar center of gravity in a stall for both airplane and bird, and remedies for the flat spin and for falling in a stall are discussed.

A note following the article explains how the controls are reversed. *Les Ailes*, November 11, 1938, page 7, 11 illus.

Some Notes on the Design of Fast Fighting Aeroplanes. R. L. Lickley. Aerodynamic, structural and general problems arising in the design of fighters are discussed in detail including: body shape; radiators and exhausts; stability and control; take-off, climb and ceiling; and wing and fuselage structure. Author is with the Hawker Aircraft company. Photographs show wing structure of the Hurricane nose of a Heinkel single-seater fighter with buried and aircooled exhausts, and nose of the Hurricane with duct cooling and latest type of exhausts. *Aeroplane*, November 9, 1938, pages 561–564, 5 illus.

Stress Analysis and Structures

Tapered Beams. E. H. Atkins. Theory of tapered beams is extended to types of girders with continuous webs which are of special interest in connection with wing, tail plane and fin spars. Formulas are developed for stresses and deflections for the simple rectangular cross section with an example of the tapered cantilever beam considered for a uniformly distributed load and for a single load of 450 lb. at the tip. Formulas for stress and deflections are also developed for tapered beams with uniform thin webs and concentrated booms tapering linearly to nothing at the apex. Examples of continuous and concentrated loads are given. Continued. *Aircraft Engineering*, November, 1938, pages 347–351, 9 illus., 4 tables, 24 equations.

Alighting Gear

For Better Braking. Bendix Two Leading Shoe aircraft brakes. Description of brake which will be used on the DeHavilland D.H.95 airplane in conjunction with the Bendix differential hydraulic gear. *Flight*, November 10, 1938, page 433, 2 illus.

Aircraft Manufacture

American Methods of Aircraft Production. T. P. Wright. Aim of manufacturing in America; factors involved in cost reduction; size of American aircraft industry; materials at present being used (wood, alloy steels, nonferrous metals, aluminum alloys, magnesium, plastics, stainless steel, forgings, castings, and extrusions); works organization and duties of the engineering and planning departments; factory organization; processes and methods including cutting, forming, machine-shop practice, processing, final assembly and inspection; type of construction; general needs in which American airplane industry can be improved; and features which have contributed substantially to economical construction in America. Curtiss-Wright P-36A Army pursuit, SB-3 Navy Scout bomber, YLA-18 Army attack airplanes, parts of the attack model being fabricated, and operations on these aircraft are illustrated. *Royal Aeronautical Soc.*, Preprint for Meeting, November 9, 1938, 88 pages, 127 illus., 6 tables.

Aircraft Performance

Private Flying. Whole secret of forced-landing safety is considered to lie in the use of a certain proportion of the flap movement during the early part of the approach and in keeping always, in reserve, the rest of the movement for last-minute height adjustment. Flap technique, variable flap control, and advantages of the old type of light airplane are discussed. *Flight*, November 3, 1938, pages 381–382.

Aircraft

Coastal Defense—An All-Purpose Type. Potentialities of machines like the Lockheed 14 airplanes on order for the R.A.F. suggest the adoption of an all-purpose coastal defense machine—a high-powered twin-engined type fitted for long-range reconnaissance, patrol and convoy work, bombing and torpedo dropping. Within the next two or three years all Fleet fighters, excepting specialized catapult types, will probably be monoplanes, but biplanes are likely to be operating with the Fleet for some time.

No replacement type has yet been announced for the Shark and Swordfish torpedo spotter reconnaissance types, and the Gloster Gladiator has been developed into a Fleet fighter. Gladiators would be very acceptable as replacements for the Nimrods but it must be assumed that they would be "interim replacements," for their performance can hardly compare with that of the new Cyclone-engined Brewsters on order for the U. S. Navy. Brief editorials. *Flight*, October 27, 1938, page 351.

FRANCE

Aircraft in Test. Brief references only to the following military aircraft in test: First issue—Dewoitine D-520 fighter of the new program (Hispano-Suiza 12-Ycrs engine cannon, 14-sq. meter wing surface, weight around 2200 kg.). Latécoère 570 bomber fitted with two new Hispano-Suiza 14-AA 1150-hp. engines provided with large cooling ribs and a new oil circulation. Morane-Saulnier M.S.-430 two-seater trainer for piloting modern aircraft (Salmson 9-Ag 390-hp. engine). Marcel-Bloch 151 two-cannon fighter (Gnôme Rhône 14-N.11 engine). Galtier single-seater fighter of wood (Hispano-Suiza 12Xcrs). Latécoère 611 cruiser flying boat (four Gnôme Rhône 1050-hp. engines) of the same program as the Potez-Cams 141 and Bréquet 730, and possibly attaining a speed around 350 km./hr. Caudron C-714 single-seater fighter (Renault 450-hp. engine) being very maneuverable, and showing good performance, of a little higher level than that of the M.S.-406.

Second issue—Galtier 30 single-seater pursuit of wood construction (Hispano-Suiza 12Xcrs engine). Bloch 180 flying boat (two Gnôme Rhône 14-N.11 engines) taking off at a total weight of 11,500 kg. N.C.-510 three-seater (two Gnôme-Rhône K9 engines). Romano 110 three-seater light defense airplane (two Renault 450-hp. engines). Dewoitine 520 pursuit (Hispano-Suiza 12-Ycrs engine cannon), having a structure especially studied for rapid construction (in 6500 hr. of work), and possibly passing a speed of 500 km./hr. at 4000 meters, and having a sufficiently high coefficient of safety for carrying groups of 1100-hp. engines. Koolhoven F.K.-58 single-seater pursuit (Hispano-Suiza 14-AA 1100-hp. engine) will attain 800 km./-hr. in a dive. Characteristics and performances of the latter are given.

Third issue—Latécoère 570 bomber (two Hispano-Suiza 14-AA engines). Morane-Saulnier 430 two-seater trainer (Salmson engine). LeO-45 bomber (two Gnôme-Rhône 14-N21 engines). Hanriot 232 trainer (two Salmson engines). Morane-Saulnier 350 biplane (Renault 6-Q 220-hp. engine) specially designed for aerobatics. *Les Ailes*, October 6, 13, and 20, 1938, pages 9, 9, 9.

Airplanes in Test. Brief references only to military aircraft in test. Hanriot 510 three-seater will be equipped with two Gnôme-Rhône 14 Mars engines and will have its fuselage reinforced. Dewoitine 514 has been specially designed and arranged for the launching of parachutes at high speed. Amiot 350 bomber (the old 340) has been equipped with two Gnôme Rhône 14-N.20/21 1050-hp. engines with which a maximum speed of 500 km./hr. is hoped for. Some modifications have been made, including especially a double vertical stabilizer to permit firing to the rear. Breguet 691 twin-engined attack and light bomber, Koolhoven F.K.58 single-seater pursuit (Hispano-Suiza 14-AA engine), and Amiot 150 twin-engined float seaplane for reconnaissance and bombardment are mentioned. *Les Ailes*, November 10, 1938, page 9.

C. A. O. 300 Training Seaplane. Two-seater side-by-side seaplane for instruction of beginners and for training in radio operation and acrobatics. Constructed of wood it is easily fabricated and repaired. Salmson 280-hp. pusher engine located above the wing. Speed 200 km./hr. Long description, characteristics, performance. *Les Ailes*, November 10, 1938, page 9, 2 illus.

New Military Aircraft. N.C. 470 five-seater training airplane for instruction in machine-gun firing, bomb release, and navigation. Two Gnôme Rhône 9AKX 480-hp. 9-cylinder aircooled engine. Maximum speed 212 km./hr. at 1000 meters. Cruising speed 180 km./hr. Description armament, characteristics, and performance with both the 9AKX and the K-9 engines.

Lioré et Olivier LeO.45 four-seater heavy bomber. Two Gnôme Rhône 14 No. 14-cylinder 1200-hp. double-row radial engines. Maximum speed 480 km./hr. at 4000 meters. Cruising speed 405 km./hr. Range 1200–2300 km. Description, armament and similar data. Photograph of the Hanriot H.232 two-seater training plane shown. *Luftwehr*, September, 1938, pages 380–382, 5 illus., 2 tables.

Pursuit Airplanes of the New Program. Dewoitine D-520 single-seater pursuit (Hispano-Suiza 12-Y engine cannon), Morane 450 and C.A.O.200 are on the same program. The last, which will be exhibited at the Paris Exhibition, has a maximum speed of 550 km./hr. at 4600 meters, an altitude which it reached in 5 min. 35 sec. Theoretical ceiling is 11,000 meters. This performance has been calculated for the airplane powered with a Hispano-Suiza 12-Y31 engine developing 860 hp. at that altitude. Brief note giving characteristics also. Drawing of the Dewoitine D-520 appears on the cover. *Les Ailes*, November 10, 1938, pages 9, 1, 1 illus.

Technical Notes. Vernisse-Galtier fighter has made its first flight. The next Vernisse-Galtier prototype will be powered by two Hispano-Suize 12Y engines driving, by a Vernisse-Waseige transmission, two concentric propellers rotating in opposite directions. This airplane, the Vernisse-Galtier V.G.-30 will have a 26-sq. meters wing surface, weigh 3400 kg. and should attain a speed of 650 km./hr. Pilot will be placed between front and rear engines.

Another prototype will have four engines, and will no doubt be the Vernisse-Galtier V.G.50 which should attain 750 km./hr. No details are released about the model of the Vernisse-Wibault four-engined transport, the Vernisse-Guyot helicopter or about the Vernisse-Waseige engine. A fighter of 3400 kg. and a four-engined racing airplane present serious problems of production and price. Short note. *Les Ailes*, October 6, 1938, page 7.

GERMANY

Dornier Do-26 Flying Boat. New DO-26 four-engined flying boat, developed for 5600-mile-range transatlantic air-mail service, has retractable wing floats. Four Junkers Jumo engines are arranged in tandem, rear engines and pusher propellers being tiltable upward at an angle of 10°. Maximum speed 208 m.p.h. Cruising speed 193 m.p.h. Description. *Aero Digest*, November, 1938, page 103, 4 illus., 1 table.

Gotha G-150 Bimotored Airplane. A. Frachet. Extremely light airplane weighing only 500 kg. empty, transports two or three people and with supplementary tanks its range can be increased from 800 to 1600 km. Powered by two Zuendapp 50-hp. engines, the airplane has a speed of 205 km./hr. Long description. *Les Ailes*, October 20, 1938, page 9, 3 illus., 1 table.

Fieseler Jung-Tiger. Fieseler Fi.99 Jung-Tiger low-wing three-seater cabin monoplane. HM.506A 160-hp. engine. Maximum speed 236 km./hr. Cruising speed 200 km./hr. Landing speed 75 km./hr. Maximum range 920 km. Description, characteristics, performance. *Luftwissen*, September, 1938, page 330, 1 illus., 1 table.

A German Touring Aeroplane. Siebel Fh-104A medium powered twin-engined five-seater monoplane is approximately in the same class as the British DeHavilland Rapide and Percival Q.6 but is faster and higher powered and has considerably less passenger space. In the Third Raduno del Littorio the Fh-104A was flown in competition with its full load of five passengers attaining a maximum speed of 200.24 m.p.h. and cruising speed of 195.6 m.p.h. Machine also put up the best average over a 994-mile course and was brought to rest over a 33-ft. obstacle in 84 yards. Prototype was fitted with two HM-508H inverted vee engines of 170/240 hp. but any similar aircooled engines up to 280 hp. may be fitted. Long description, characteristics, performance, and cutaway drawing showing structure and location of equipment. *Aircraft Engineering*, November, 1938, pages 354–355, 4 illus., 1 table.

New Military Aircraft. Blohm and Voss Ha140 three-seater high-seas float seaplane for long-distance scouting and torpedo and bomb carrying. Two B.M.W. 132.Dc 800-hp. aircooled 9-cylinder radial engines. Maximum speed 320 km./hr. Time to climb to 3000 meters 11.5 min. Cruising speed 295 km./hr. Maximum range 2500 km. Description, armament, characteristics, performance. *Luftwehr*, September, 1938, page 38, 1 illus., 1 table.

GREAT BRITAIN

C. A. G. Vanguard. Impressions in flying the first of the production Tipsy two-seaters which is said to have a really useful performance and almost a pusher view. Design details are also discussed and characteristics given. *Flight*, August 11, 1938, pages 122c–122d, 123, 5 illus.

Specifications of the Standard Vickers Wellesley Monoplane. Standard Wellesley two-seater long-range bomber landplane is of geodetic construction, has two machine guns and carries bombs in external containers slung below the wings. Bomb load up to 2000 lb. Bristol Pegasus XX supercharged 925-hp. engine. Maximum speed 228 m.p.h. at 19,680 ft. Cruising speed 188 m.p.h. at 15,000 ft. Maximum range, overload, 38 percent power 2590 miles. Ceiling 32,250 ft. Description, characteristics (including weights and bomb loads) and performance. *Aeroplane*, November 9, 1938, page 548a, 3 illus., 1 table.

Triple Triumph. Distance of 7162 miles nonstop (Ismailia, Egypt, to Darwin) was covered by two of the three special Vickers Wellesley monoplanes of the Long-Range Development Unit in 48 hours, beating by 856 miles the world's long-distance record set by the Russians. Average speed was 150 m.p.h. The third Wellesley landed at Timor 400 miles from Darwin. Special Wellesley differs from the standard Service type, uses a Pegasus XXII 1010-hp. engine, and Rotol propeller, and is fitted with additional tankage in the wing. Forward part of fuselage is slightly increased in width, and use is made of a gilled long-chord cowling in conjunction with special fairings. All-up weight is approximately 19,000 lb., against 11,000 lb. of the standard Service type. Wing and fuselage are of geodetic construction, wing having a very high aspect ratio.

Description of airplane and equipment, explanation of geodetic construction principle with drawing, and parts from radio messages received by the British Air Ministry during the flight. *Flight*, November 10, 1938, pages 426–428, 4 illus.

Account of flight, modifications to the airplane and engine (which was given higher compression ratio and used a lead-free 100-octane fuel), wing loading (30.2 lb./sq.ft.), and details of the standard Pegasus XXII engine. Specifications of the standard Vickers Wellesley monoplane also given. Photographs show duralumin hoop girders transferring dead loads from fuselage to wing. *Aeroplane*, November 9, 1938, pages 547–548, 6 illus.

The Heavy Brigade. Take-off weight of the eight modified Empire flying boats of the Cabot class is 46,000 lb. compared with 40,500 lb. of the original, and 3500 lb. of the weight is for payload. Those equipped for refueling in the air may load up to 53,000 lb. All have Bristol Perseus sleeve-valve engines. Few details. *Aeroplane*, November 2, 1938, page 540.

Latest Jumping Autogiro. Cierva C.40 latest direct-lift two-seater autogiro. Driving torque is applied to the rotor through a system of levers which move the blades beyond their normal position to an incidence which provides no lift and minimum profile drag. They are driven to about 285 r.p.m. and when clutch is released, disconnecting the drive from the motor, restoring moment caused by centrifugal force causes the blades to move around their hinges to normal incidence. Change in pitch produces lift in excess of weight of machine and aircraft is projected vertically upward and then proceeds as a normal autogiro. On landing application of the rotor brake sets into operation a system of epicyclic gears causing the blades to move into no-lift position. All-up weight 1950 lb. Tare weight 1350 lb. Maximum speed 120 m.p.h. Cruising speed 100 m.p.h. and range 200 miles. Description. *Aeroplane*, November 2, 1938, page 537, 2 illus.

Brief note on C.40 autogiros which have been ordered for British Army and Fleet Air Arm. *Flight*, November 3, 1938, page 382, 2 illus.

"Mercury" Makes Good. Ireland-Montreal-New York flight of the Mercury on July 21 is considered as the first commercial vindication of the Mayo-Composite scheme. List of manufacturers whose materials and equipment were used in the Mercury and lower component Maia and account of flight. *Flight*, July 28, 1938, pages 79–80, 3 illus.

British Military Aircraft. Few details and in some cases characteristics, performance and armament are given for service equipment in use in the R.A.F., including: Airspeed Oxford advanced trainer. Armstrong-Whitworth Whitley III (A.W.38) twin-engined bomber. Avro Anson twin-engined general reconnaissance and advanced trainer. Blackburn Skua two-seater fleet fighter dive bomber monoplane and Shark II biplane for torpedo dropping. Bristol Blenheim high-speed twin-engined bomber and Bombay bomber transport. DeHavilland Tiger Moth trainer, Queen Bee radio-controlled target airplane, and Don communications type airplane. Fairey Battle single-engined bomber, the Baby Battle (P.4/34) light bomber, Swordfish two-three-seater torpedo-spotter reconnaissance biplane and Sea'ox light two-seater catapultable reconnaissance. Gloster Gladiator biplane fighter, and a low-wing multigun fighter monoplane (F.5/34) of stressed skin construction and designed to take the Bristol Mercury or Perseus engines. Handley-Page Harrow and Hampden twin-engined bombers. Hawker Hurricane, and Henley two-seater bomber for target towing. Miles Kestrel trainer, and Magister two-seater for ab initio training. Saunders-Roe London twin-engined flying boat for open-sea reconnaissance and coastal defense. Short Sunderland long-range military flying boat. Supermarine Spitfire multigun single-seater fighter, said to be the fastest military machine used as standard by any Air Force (photograph and few details only), and the Stranraer twin-engined flying boat. Vickers Wellesley single-engined long-range bomber, torpedo carrier or general-purpose aircraft, and Wellington twin-engined bomber. Westland Lysander army cooperation monoplanes. Armament and performance are given for some of the above aircraft. Many photographs are given, one illustrating the Nash and Thompson power-driven turret on a Hawker Demon two-seater fighter, and another the Fairey P.4/34 high-speed light bomber in flight. *Flight*, October 27, 1938, pages 362a–362l, 363–365, 33 illus.

British Commercial Aircraft. Airspeed Envoy III; Armstrong-Whitworth A.W.27 Ensign; Avro 652; Cunliffe-Owen Burnelli; DeHavilland D.H. 95, D.H. 91 (Albatross), D.H. Rapide, and D.H. 86; General Aircraft Monospar Universal; Heston Series II engined Phoenix; Percival Q.6; Pobjoy-Short Scion; Short Empire flying boats; and Mayo Mercury seaplane. Data and photographs of these transports. *Flight*, October 27, 1938, pages 355–360, 10 illus.

British Sport and Training Types. Descriptions of light aircraft produced by 15 firms including the Arpin pusher. *Flight*, October 27, 1938, pages 367–374, 15 illus.

Comper Scamp light high-wing single-seater. Description. *Flight*, July 28, 1938, pages 81–82, 2 illus.

Few details of new Moth Minor. *Flight*, August 4, 1938, pages 97, 94, 1 illus.

A Revised Blenheim. Improved Bristol Blenheim bomber has a new nose extending the length by 3 ft. and giving exceptional field of view. Same crew of pilot, navigator, and radio operator, gunner and same load of bombs are carried. Range is brought up to 1900 miles and top speed to 295 m.p.h. Two Mercury VIII engines give 920 hp. for take-off on 100-octane fuel. In its new form Blenheim is considered "a considerably more effective weapon than, for example, the latest version of the German Dornier Do.17 with which the type is usually compared." Short description of improvements. *Flight*, November 3, 1938, pages 383, 380, 3 illus.

HOLLAND

Fokker Is Constructing a Torpedo-Carrying Seaplane. Improved version of the Fokker T-8-W torpedo-carrying seaplane under construction is designed more particularly for coast defense, observation, and patrol. It is a three-seater float biplane with unequal wings. Front part of fuselage is a monocoque of duralumin, central part a monocoque of wood, and rear part of steel tubes and fabric covering. Wings of wood are insubmergible. Bombs and torpedoes are carried in a special compartment below the wing in the fuselage and opened by hydraulic control, electrically operated. Duralumin floats form six pressure compartments. Armament and a few other details. Two 400 to 700-hp. engines. *Les Ailes*, October 20, 1938, page 5.

Fokker S-9 Two-Seater Trainer. A. Frachet. Fokker S-9 trainer for beginners is capable also of serving advanced pilots in perfecting aerobatics. It can be powered by either an inline or radial engine of 160 hp. and will climb to 1000 meters in 5 min. With Menasco 168-hp. engine, maximum speed is 193 km./hr. and range 750 km. With Siddeley Genet-Major 165-hp. engine, maximum speed is 180 km./hr. Long description, characteristics, and performances with both types of engines. *Les Ailes*, October 13, 1938, page 9, 3 illus., 1 table.

New Military Aircraft. *Koolhoven F.K.58* single-seater pursuit airplane. Hispano-Suiza 14AA.10 1080-hp. engine. Maximum speed 490 km./hr. at 4000 meters. Cruising speed 440 km./hr. at 4000 meters. Time to climb to 7000 meters 8.2 min. Range 720 km. Koolhoven F.K.55 single-seater pursuit airplane. Lorraine Sterna 12-cylinder vee 1000-hp. engine (1350 hp. for take-off). Maximum speed 510 km./hr. at 3600 meters. Cruising speed 450 km./hr. at same height. Rate of climb to 3200 meters 13.5 meters per second. Range 1000 km. Description, armament, characteristics, and performance of both airplanes. *Luftwehr*, September, 1938, pages 383–385, 4 illus., 2 tables.

ITALY

The Height Record. World's Height Record for airplanes was beaten on October 23 by a flight to 56,017 ft. Lt. Col. M. Pezzi, Commander of the High-Flying Section of the Royal Italian Air Force Experimental Establishment, broke the record in a Caproni biplane having a special Piaggio engine and sealed cabin. Flight took 1 hr. 45 min. Minimum temperature registered 59°C. below zero. Italy is the first to try out the hermetically-sealed cabin above 40,000 ft. Brief note. *Aeroplane*, October 26, 1938, page 489.

U. S. A.

New Military Aircraft. Seversky P-35 pursuit airplane and Consolidated PBY-1 six-seater bomber flying boat. Description, armament, characteristics, and performance. Consolidated XPB2Y-1 flying boat is illustrated. *Luftwehr*, September, 1938, pages 385–388, 9 illus.

Continental-Powered Cub Coupe. General characteristics and performances are listed for the models of the Piper Cub, including the Trainer Sport J-3 (Continental A-40 engine), three models of the Sport powered by the Franklin 50, Continental A-50, and Lenape 50 engines, respectively, and Coupe (Continental A-50 engine). Table and photograph only. *Aero Digest*, November, 1938, page 20, 1 illus., 1 table.

D.C.4 Facts. Out of a gross weight of 65,000 lb., a total of 3348 lb. is taken in the main wheel undercarriage with its retraction gear, and another 664 lb. must be added for weight of the nosewheel with its fittings and retraction gear. On test the maximum impact force for the main undercarriage reached 120,000 lb. and 54,000 lb. for the nosewheel. Brief note only on weight figures. *Flight*, August 11, 1938, page 129.

Pilot's Compartment of the Douglas DC-4. Compartment is illustrated in a diagram divided into 21 sections, and instruments and their location in each section are listed. *Aero Digest*, November 1938, page 74, 2 illus.

Air Transportation

German North Atlantic Flights. Return flight of the Ha.139 Nordstern seaplane (four Junkers heavy-oil engines) and a review of the other 14 return flights made by the Deutsche Luft Hansa aircraft. Short Note. *Aeroplane*, October 26, 1938, page 509.

Less Comprehensible. Disadvantages of the site at Southampton which has been selected as a permanent base for the Empire flying boat service, and advantages of Langston Harbor. Editorial. *Flight*, August 4, 1938, pages 94–95, 110.

Maps indicating the Southampton and Langston schemes. *Flight* August 11, 1938, page 128, 2 illus.

North Atlantic Air Mail Service. Experimental air mail service across the North Atlantic will begin next spring as soon as the seaplane base at Botwood, Newfoundland, is clear of ice, according to a British Air Ministry announcement. Inauguration will depend on results of air refueling trials to be carried out by the "Cabot," one of the strengthened Empire flying boats. Brief reference. *Engineer*, November 18, 1938, page 563.

Subsidies on Side Lines. New subsidy arrangements for the Bermuda-U. S. A. and Bangkok-Hong Kong services of Imperial Airways. *Aeroplane*, November 9, 1938, page 585.

Airships

Graf Zeppelin. Description, from actual inspection, of the constructional features and accommodations of Germany's latest dirigible. Drawings illustrate these accommodations, as well as a typical joint of structural members showing attachment of radial wires, and a two-page view of the construction of the Graf Zeppelin. *Flight*, November 10, 1938, pages 416–419, 6 illus.

Balloons

Polish Stratosphere Balloon Was Burned on the Ground. Balloon had been inflated in the afternoon of October 13 preparatory to take-off early the following day when the wind increased and toward morning the order for deflation was given. During deflation the gas caught fire and the balloon started burning. Due to precautions previously taken the fire was rapidly subdued. Damage to the upper part of the envelope, however, was sufficient to require important repairs taking some time.

It is thought that an electric spark was produced after the balloon was blown by the wind, and rubbed against the ground. It is possible that the spark which leaped between the envelope (charged with static electricity) and the ground was sufficient to ignite the hydrogen. Few details of the balloon are given. The pilots hoped to reach a height of 30,000 meters and beat the record of 22,066 meters won by O. A. Anderson and A. W. Stevens. *Les Ailes*, October 20, 1938, pages 3–4.

Gliders

Curious Tests of a Russian Glider with Propeller. Ultra-light glider used weighed only 55 kg. Propeller manually operated by the pilot prolongs the flights from 60 to 150 meters. Description. *Les Ailes*, October 6, 1938, pages 12–13, 2 illus.

Propellers

Airplane Propeller Blade Life. J. B. Johnson and T. T. Oberg. Results of tests recently completed at Wright Field on two blades manufactured from the same aluminum alloy and representative of modern forging practice, one having 21 hours' service and the other 4233 hours' flying time. Grain size and distribution, microstructure, S-N damage diagram and transition velocity curves obtained by Watertown Arsenal are illustrated and discussed and average properties are shown in a table. Data indicate that an aluminum forging alloy of that chemical composition and heat treatment is not damaged by overstress. *Metals & Alloys*, October, 1938, pages 259–262, 8 illus., 1 table.

The de Lavaud Airscrew. Thrust is the main operating force and centrifugal action is used in a secondary way to help control it. When propeller is turning thrust tends to make the blade advance. It is governed by flexibility of a torsion bar and by centrifugal force which tends to keep the blade flat in the plane of rotation. Blade at rest is in the correct coarse pitch for rated height, r.p.m., and speed and moves forward when the engine is run up thereby decreasing its pitch according to amount of thrust. Long description of the de Lavaud propeller and of a flight in a Miles Monarch airplane powered by a Gipsy Major fitted with this propeller. *Aeroplane*, October 26, 1938, pages 511–512, 4 illus.

A New Technique for Vibration Study. New procedure developed by Hamilton Standard Propellers Division. Propeller behavior may be predicted from a knowledge of vibration stresses at any point on the propeller during actual operation. Method is based on the phenomenon that certain materials increase and decrease their electrical resistance in direct proportion to stresses imposed on them. Resistor or strain gage is cemented longitudinally on the blade and insulated from it electrically and two fine wires are led to a source of direct current. Ground and flight installations of the device, use in locating other sources of trouble, effectiveness of technique for determining and controlling vibration stresses, and early experimentation are discussed. Equipment is being used on the Douglas DC-4 and Boeing 314. *Aero Digest*, November, 1938, pages 80, 83–84, 7 illus.

A Visit to the Ratier Plant at Figeac. M. Victor. Processes employed at the Figeac decentralized plant in the production of Ratier metal propellers are described, including heat treatment of the blades and machining of the hub. Rate of production at Figeac is 30 propellers per month but the French Air Minister has requested Ratier to build a new plant. *Les Ailes*, November 10, 1938, pages 8–9.

Miscellaneous

The Lilienthal-Gesellschaft Conference. C. G. Grey. First issue—Brief list of papers presented, and general account of the meeting. Second issue—Impressions of the Heinkel factory, its school for apprentices, and German trade, with only a brief reference to German aircraft production. *Aeroplane*, October 26 and November 2, 1938, pages 493–495 and 525–527, 6 illus.

The Dangers of Lightning. A. and K. Wegener. Dangers to which kites, free and captive balloons, airships and airplanes are exposed from atmospheric electricity. *Les Ailes*, October 6, 1938, page 7.

Airworthiness of Aircraft. H. Engelmann. Airworthiness as set forth in German government requirements from August, 1922 to 1936. Definitions, test places for aircraft, testing of airworthiness, design testing, flight performance, construction and test requirements, and nature and purpose of technical specifications. *Luftwissen*, September, 1938, pages 331–336, 4 illus.

Striking Advances Previewed at Aircraft Production Forum. C. F. McReynolds. Account of the National Aircraft Production Meeting in Los Angeles with brief reviews of papers presented and discussion. *S.A.E. Jour.*, November, 1938, pages 10, 18–20.

Aircraft Instruments

The Absolute Altimeter. H. W. Roberts. Western-Bell-United Air Lines absolute altimeter is based on A. T. & T. patents of L. Espenschied. Small 5-watt transmitter feeds a continuous ultra-high-frequency signal through a coaxial feed line to a small balanced dipole antenna beneath the fuselage whereby radiation is directed toward the ground where it is reflected and received by a similar antenna on board the airplane. Long description of altimeter tested on the Boeing flight research airplane. Research work now being undertaken and plans for applying the altimeter principles to give warning of possible collision with other aircraft in flight are mentioned. *Aero Digest*, November, 1938, pages 87, 105, 2 illus.

Cloud-Base Height at a Glance. Fox cloud-base recorder consists of an ordinary wet-bulb and dry-bulb hygrometer for measuring humidity of air before it starts upward. Central drum is rotated until pointer comes in line with temperature on the scale of the dry-bulb thermometer. Height of cloud base is indicated on the diagonal line of the drum coincident with the height of the mercury in the central wet-bulb thermometer. Short description of device used by a sailplane pilot and said to be accurate on almost any kind of a day. *Flight*, August 4, 1938, page 102, 1 illus.

Gasoline Flow Meter. Mile-O-Meter remote-control gasoline flow meter for indicating amount of fuel being consumed at a given r.p.m. or speed. Meter shows amount of fuel passing through a measuring unit, indications being transmitted electrically to a dial reading in gal./hr. Few details. *Aero Digest*, November, 1938, p. 91.

Boosting the Bourdon. Boost gage developed by Barnet Instruments, Ltd., for aircraft boost-gage work uses three Bourdon tubes mounted side by side in parallel. Dial is graduated from −4 lb. to +8 lb. In order that condensed fuel may be drawn off, a small extension pipe is arranged leading up back of the casing from the bottom to the vacuum pressure pipe union. Whenever throttle is closed, the resultant drop in pressure will cause any condensed fuel collected in the bottom of the instrument to be drawn off and led back to the engine induction system. Short description. *Flight*, November 10, 1938, page 434, 2 illus.

Ice Elimination Equipment

De-Icing. Goodrich deicers were not liked by British pilots because the first were not properly fitted and had an uncomfortable habit of breaking loose. The Bulloch invention is considered the most promising of all. This consists in forming leading edges of wings, tailplane and fins of a sheet material composed of monel-metal wire woven with flax and permeated with a nonfreezing liquid pumped from the fuselage. Dunlop deicer is referred to with the comment that not much has been heard of it lately. Kilfrost paste used by Imperial Airways is also briefly discussed with illustrations showing ice forming over Kilfrost on a wind-tunnel model combining a leading edge and slotted aileron. Short article. *Aeroplane*, October 26, 1938, page 490, 3 illus.

The Formation of Ice on Aircraft. J. Dentan. Study of the phenomena of ice formation, and means for protecting aircraft against icing. Mechanisms of formation of different types of ice are discussed, in regard to initial conditions corresponding to a metastable equilibrium for several cases. Importance of icing and speed of the formation is shown, especially the effect of humidity on speed of the airplane and the angle of inclination of the surface, and speed of formation of the ice.

Second section discusses means for protection against icing, including: prediction of icing, warning and indicators of icing, and natural removal of the ice; and effects of icing on the airplanes. Arrangements suitable to aircraft for contending with the formation or accumulation of ice are described covering: thermal methods utilizing exhaust gases and electrical heating; mechanical methods; and chemical methods giving protection by coating and by soluble mixtures. Drawing shows installation of the Goodrich system on the Bloch 220, French equipment, and the TWA Goodrich system. N.A.C.A. and foreign results are discussed. Concluded. *L'Aéronautique*, October, 1938, pages 207–210 and 211–220, 14 illus., equations.

Miscellaneous Equipment

Arc Welding in Aircraft Heating. L. J. Carey and M. Whitlock. Difficulties experienced with boilers for heating cabins on American Airlines' airplanes, and welding experiments undertaken by the Airline on a Lincoln arc welder machine in the construction of boilers. Fabrication of the tubular section is achieved by bending $\frac{1}{2}$-in. D.X. 065 W. stainless-steel tubing into shape and bringing tubing ends through the $\frac{3}{8}$-in. header plates so that they protrude on the opposite side for about $\frac{1}{8}$ in. Tubes are welded to the top side of the header plates and the protrusion of tubing burnt off. Weld starts out as a filler weld but actually develops into a corner weld. Boilers of this type averaged 376 hr. flying compared with 75 hr. previously. Costs of DST and DC-3 boilers of both types are compared. Parts of the Lincoln Arc Welding Foundation prize paper. *Aero Digest*, November, 1938, pages 52, 55, 102, 4 illus., 1 table.

Positive-Displacement Meter for Motor Fuels. Tecalemeter having special compensation for volumetric variations due to temperature changes. Air and water eliminators also have been designed for use with the device when metering fuels. Meter consists of four cylinders arranged at right angles in the same horizontal plane in which reciprocate four metering pistons linked in pairs by connecting rods. Correction for temperature changes in the liquid is effected by a bellows thermostat controlling an intermediate gear in the drive to the counter mechanism. Long description. *Engineering*, October 28, 1938, pages 500–502, 5 illus.

Couplings for High-Pressure Hose Lines. By means of the Argus coupling, lines carrying a liquid under pressure can be separated without loss of liquid in the line. Soiling of parts in separation and inclusion of air in recoupling can thus be avoided. Short description and drawing. *Luftwissen*, September, 1938, page 345, 4 illus.

An Electrical Algebraic Equation Solver. D. L. Herr and R. S. Graham. Equation solver described will give all the roots of an algebraic equation of the eighth degree or less having real coefficients. A simple extension of the present apparatus will permit solution of equations, with complex coefficients, of any degree. Machine was developed as a Moore School Research project. *Rev. Scientific Instruments*, October, 1938, pages 310–315, 9 illus., 5 equations.

Parachutes

A New Type of Pressure Suit. New type of pressure suit designed by Dr. Garsaux permits the occupant of an airplane to make a parachute jump at very high altitudes. Suit was tested in a low-pressure chamber by Dr. Richou and the parachutist Denois. Brief reference. *Les Ailes*, November 10, 1938, page 3.

In U. S. S. R. The Doronine Brothers have invented a parachute device which permits the parachute to open automatically in the desired interval

of time (from 5 to 128 seconds), according to newspaper reports. Tests are said to have been completely satisfactory. Brief reference. *Les Ailes*, October 6, 1938, page 5.

Self-Opening Parachute. No pulling of ripcord is necessary on the new parachute invented by R. H. Hart. As the jumper falls, the parachute pack swings up over his head and air rushing past him catches in a pocket, bellows it out, and pulls the ripcord automatically to open the parachute. Flaps on each side of the parachute make it much more maneuverable and they can be opened and closed by pulling on the steering shrouds. Brief references. *Science News Letter*, November 5, 1938, pages 294–295, 3 illus.

Testing Apparatus

The Electric Strain Gage. M. A. Rusher and A. V. Mershon. Electric strain gage can be used to record accurately strains as low as 0.00001 in. whether these are static or a·e oscillatory at frequencies up to at least 500 cycles per second, and the single-line trace allows several measurements to be recorded simultaneously. Electric strain gages, their calibration, and results obtained are described. *Electrical Engineering*, November, 1938, pages 645–648, 7 illus., 1 table.

The Use of the High-Vacuum Cathode-Ray Tube for Recording High-Speed Transient Phenomena. Capt. D. I. McGillewie. Portable apparatus operated from a 50-cycle a.c. mains and devised for visual examination and or photographic recording of controlled or uncontrolled high-speed transient phenomena. Long description.

A second article is entitled "Recurrent-Surge Oscillographs, and Their Application to Short-Time Transient Phenomena," by K. J. R. Wilkinson. *Instn. Electrical Engrs. Jour.*, November, 1938, pages 657–662, 663–672, and (disc.) 673–680, 22 illus., 10 equations.

Materials of Aircraft Construction. H. J. Gough. Paper previously abstracted from preprint. *Jour. Royal Aeronautical Soc.*, November, 1938, pages 922–1031, 37 illus., 12 tables.

The National Physical Laboratory. Work on the thermal properties of metals, and on building and insulating materials, refrigeration, evaporation, and thermal insulation. Research in the Physics Department. *Engineering*, November 18, 1938, pages 594–596, 3 illus., 1 table.

Metals

Automotive Bearing Materials and Their Application. A. F. Underwood. Paper previously abstracted from preprint. *S.A.E. Jour. (Trans.)*, September, 1938, pages 385–392, 13 illus.

Creep of Metal Under Static and Repeated Stresses. F. C. Lea. Preliminary experimental results on creep are described. Advantages of the torsion test; importance of total strain produced in a given time and of final rate of creep in creep tests; research on pipe flanges carried out at the National Physical Laboratory; and importance of periodicity of stress. Abstract of Midland Metallurgical Societies paper. *Iron Age*, November 17, 1938, pages 39–41, 1 illus.

The 20th National Metal Congress and Exposition. Technical programs of the American Society for Metals, the Iron and Steel and Institute of Metals Divisions of the A.I.M.M.E., the Wire Association, and the American Welding Society. Also list of e hibitors and exhibitions. *Metals & Alloys, Sup.*, October, 1938, pages 1–84.

Metals and Lubricants for Bearings and Gears—An Extended Abstract. R. W. Dayton. Piston rings and cylinders; wear in internal-combustion engines; gears; E.P. lubricants; wire drawing; cold pressing of sheet steel; cutting fluids; and chains and wire ropes. Concluded. *Metals & Alloys*, October, 1938, pages 281–285, 8 illus.

Corrosion and Protective Coatings

Corrosion-Resisting Materials—A Review of Those Relevant to Aircraft Construction. F. A. Fox. Bimetal galvanic attack, pitting, concentration or solution cells, corrosion cracking ("season" cracking) and corrosion fatigue are explained. Forms of corrosion to which magnesium and aluminum, their alloys, iron and steels, stainless steels and nickel alloys are subject are discussed in detail with regard to their suitability as materials for aircraft and aircraft engines. Metal protection and use of cadmium plating are also considered. *Flight, Aircraft Engr. Sup.*, July 28, 1938, pages 49–52.

Iron and Steel

The Metallurgical Story of the Ford Centrifugally Cast Steel Gears. E. F. Cone. Composition of the gears, centrifugal machines, heat-treatment cycle, and macro- and micro-structure. *Metals & Alloys*, October, 1938, pages 275–279, 9 illus., 2 tables.

The Present Status of the Low Alloy High Strength Steels—A Survey. E. F. Cone. Survey of field of application of most of the steels, present status as to composition or any material changes in the original steels, and description of the newer steels. Discussion covers: nickel steels; Cromansil; manganese-vanadium; molybdenum Cor-Ten, Man-Ten, and Sil-Ten; Yoloy; Republic double strength Grades 1 and 1A; Inland Hi-Steel; Armco H.T.-50; Jal-Ten; Mayari R; A.W. Dyn-El; and Great Lakes high-tensile steel. Survey of replies to a questionnaire. *Metals & Alloys*, October, 1938, pages 243–254, 21 illus., 5 tables.

Steels for Aircraft. W. H. Hatfield. Composition, tensile strength, and other characteristics and applications are shown for 22 steels commonly used in British powerplant units and 18 steels used in British aircraft. General trend of modern steel technology in relation to aircraft construction is discussed. Mounting of the Rolls Royce Merlin in a Hawker Hurricane is illustrated to show how stainless steel plates are used to join steel tubing. *Aeroplane*, November 9, 1938, pages 559–560, 1 illus., 2 tables.

Iron and Steel Institute (British). "Specific Heat-Temperature Curves of Commercially-Pure Iron and Certain Plain-Carbon Steels," C. Sykes and H. Evans. "Third Report of the Steel-Castings Research Committee." "Modern Rolling-Mill Practice in America," Q. Bent. "Development of Continuous Strip Mills," D. Eppelsheimer. Review of papers and discussion following. *Engineering*, November 18, 1938, pages 580–581.

Discussion following presentation of the Third Report of the Steel Castings Research Committee. *Engineer*, November 11, 1938, pages 580–581.

Nonferrous Alloys

Copper Alloys in Engineering. H. J. Miller. Materials for service at elevated temperatures. Service conditions and requirements including immunity to reducing gases, resistance to oxidation, and retention of mechanical properties; copper alloys with silver additions; welding electrode alloys; copper-chromium alloys; and copper-nickel-silicon alloys. To be continued. British Institute of Metals paper. *Metal Industry*, November 11, 1938, pages 461–464, 2 tables.

Light Alloys in Aircraft Construction. Contributed by High Duty Alloys, Ltd. Composition and physical properties of British wrought aluminum alloys and aluminum alloys for casting, and comparative strength-weight ratios of various steels and light alloys are shown in tables. Discussion covers: light alloys used in aircraft engines; piston materials; propeller blades; development of materials for aircraft construction; and improvements in manufacturing processes including control of processes, casting, forging, stamping, and welding. Drawing illustrates working temperatures at various points in a water-cooled aircraft-engine cylinder. *Aeroplane*, November 9, 1938, pages 571–574, 8 illus., 3 tables.

Light Alloys in Production. Processes in the new light-alloy (aluminum) factory of Birmetals, Ltd., including extrusion, rolling, heat treatment, preparation of billets for aluminum-coated sheets, extrusion of tubes and sections, repair shop, and laboratories. Long description. *Aircraft Engineering*, November, 1938, pages 359–361, 7 illus.

Light Metals in Aircraft Construction. R. Le Coeuvre. Discussion by C. H. Desch, H. Sutton, and others following presentation of paper before the Royal Aeronautical Society. *Metal Industry*, November 11, 1938, pages 465–466.

Magnesium Alloys. Progress in the production of magnesium with reference to recent developments showing that magnesium oxide can be produced from dolomite existing in vast quantities in England. *Aeroplane*, November 9, 1938, pages 575–576.

Abstracts of the Papers (British Institute of Metals). "Constitution of Certain Magnesium-Rich Alloys," W. Hume-Rothery and G. V. Raynor. "The Liquidus, Solidus, and Solid-Solubility Curves in Some Magnesium Alloys," (same authors). "Constitution of Aluminium-Zinc Alloys of High Purity," Marie L. V. Gayler and E. G. Sutherland. "Copper-Rich Nickel-Aluminium-Copper Alloys," W. O. Alexander. "Copper-Aluminium Alloys Made from Aluminium of Very High Purity," Marie L. V. Gayler. "Tarnishing of Silver and Silver Alloys and its Prevention," L. E. Price and G. J. Thomas. "The Mechanical Properties of Tin-Rich Antimony-Tin Alloys," D. Hanson and W. T. Pell-Walpole. *Metal Industry*, October 28, 1938, pages 416–419.

Abstracts of papers and discussions. *Engineering*, November 11, 1938, pages 566–568. *Engineer*, November 11, 1938, pages 536–537.

Light Alloys in Aircraft Construction. R. Le Coeuvre. Recent industrial developments in the use of light alloys in aircraft engines are discussed, particularly improvements in characteristics by heat treatment, development of pressure die-casting foundry and of press forging, and compression during solidification. Use of light alloys in aircraft are taken up in regard to forming and methods of assembly.

Possibilities in the new aluminum-magnesium light alloys, magnesium-rich alloys, and use of Vedal or Alclad in the construction of seaplane hulls and floats as well as the electrolytic effects which arise are considered and desiderata for designers are given.

Trends of research reviewed include: improvements of aluminum-magnesium alloys; electric spot or seam welding; heat treatment following welding; water tightness of welded seams; welding control; research on stability of automatically protected alloys in sea water; and autoprotection of magnesium-rich alloys. Means of increasing the output of aircraft by machine tools are listed. Royal Aeronautical Society paper. *Metal Industry*, November 4, 1938, pages 437–442.

Oxidation-Resistance in Copper Alloys—Production of Resistant Films. L. E. Price. An alloying constituent added to prevent high-temperature oxidation should have a sufficient affinity for oxygen, and should on heating form an oxide film of high electrical resistance. These principles provided an explanation for the good resistance to oxidation conferred on copper by additions of beryllium and aluminum and suggested a method by which it could be increased.

Growth of copper oxide films; application of Wagner's equation to oxidation of alloys covered with a film of oxide of one of the alloying elements; nature of resistant film; crystal structure of the oxide; improvement of oxidation resistance by selective oxidation; and experimental results. British Institute of Metals paper. *Metal Industry*, October 28, 1938, pages 413–416, 1 illus., 3 tables.

Welding

Form of Welded Parts in Aircraft Construction. W. Rethel. Photographs of welded aircraft parts which did not require straightening illustrate the accuracy of welding possible when shrinking processes are completed under control. Various types of joints are illustrated and discussed. Four advantages and four disadvantages of welded structural parts are pointed out. *Luftwissen*, September, 1938, pages 337–341, 22 illus.

Notes on Welding Practice. J. G. Waterhouse and A. R. Mowbray. Advantage of the rightward method of welding, effect of variation in the angle of the blowpipe, and problem of penetration of the weld. *Aircraft Engineering*, November, 1938, page 363, 3 illus.

Plastics

"Aerolite" Synthetic Glue on the Market. When a joint made with Aerolite glue is tested to destruction, it will always show a wood failure, according to claims. The glue is said to be truly waterproof and to remain completely efficient even after 18 months' immersion. Aerolite is the first glue of its kind to be approved by the British Air Ministry and is released by the approved system of inspection of Aero Research, Ltd. Brief reference. *Flight*, August 4, 1938, page 104.

Aircraft Possibilities of Cellulose Acetate Plastics. A. Klemin. Properties of Lumarith, a thermoplastic material now used for airplane windshields, and possibilities of cellulose acetate plastics for aircraft. General, physical, and chemical properties of Lumarith, available forms, fabrication possibilities, maintenance and repair, and use for nonstressed parts are described. Because of low strength properties, the author does not consider Lumarith in itself as a material for immediate application in stressed parts. Particulars of some reinforced plastic materials are quoted from Gough's paper and the advantages and possibilities of such material are considered. *Aero Digest*, November, 1938, pages 59–60, 63, 84, 6 illus.

Plastics and Production. S. C. Hart-Still. New felt-base resin is considered as the most suitable material at present available for aircraft structures, in regard to both strength and moldability, and is an impregnated rather than reinforced material. It has a fibrous felt base and uses phenolic resin. It is made by reducing the inner bark of a tree down to separate fibers and then relaying the fibers. Impregnation is effected by passing the material through a resin solution. It may be molded by forming of ribs or excrescences on a sheet of otherwise constant thickness. Properties of this material and low cost of production are discussed.

In order to determine possible economic advantages of plastic construction, two complete aircraft designs have been investigated (one a single-engined fighter type and the other a twin-engined commercial type) and principle of using more than one panel produced from a single mold was carried out. Drawings show how a semimonocoque fuselage or nacelle and a wing can be built up of standard molded components and methods of joining up the nose. *Aeroplane*, November 9, 1938, pages 580–582, 3 illus., 4 tables.

Protein Plastics from Soybean Products. G. H. Brother and L. L. McKinney. Action of hardening or tanning agents on protein material. Thermoplastic protein-formaldehyde material; effect of pH on protein-formaldehyde reaction; comparative action of commercial hardening agents; and action of formaldehyde or furfural on commercial protein material. *Industrial and Engineering Chemistry, Ind. Ed.*, November, 1938, pages 1236–1240, 2 illus., 4 tables.

Wood

The Structure of Wooden Aeroplanes. E. Percival. Airplanes up to 6000-lb. gross weight should be made of wood. Maximum value and benefit obtained from airplanes of wood, simplicity of fabrication, effects of climate on wood, cheap production obtainable, typical wooden wing construction, and the stressed skin wing are discussed. *Aeroplane*, November 9, 1938, pages 568–570, 4 illus.

Timber in the Construction of Aeroplanes. F. G. Miles. Airplanes can be built as fast, strong, stiff, and as durable in wood as in metal, they can be built more quickly, and there are unlimited supplies of suitable labor and materials. Wooden construction for military or civil aricraft of fairly light types, and as a defense measure in war are considered. Type of Miles aircraft built since 1935, present-day position of wooden construction, Italian and German military aircraft using wooden construction, and flexibility of design are discussed. *Aeroplane*, November 9, 1938, pages 565–567, 8 illus.

Miscellaneous Materials

Cement for Aircraft Construction. Improved Bostik cements for water-tighting glass and plastics in windshields and windows, and seams in wings, stabilizers, and cabins. Brief reference only to these cements and to a special line using neoprene which gives added oil and gas proofing. *Aero Digest*, November, 1938, page 91.

Fire-Proofing Material. Ignex, a watery odorless liquid used on stuffings of paper, leather, wool, cotton, kapok, and wood shavings, forms a transparent film over each fiber and prevents lumping and sagging of stuffings. Few details. *Aero Digest*, November, 1938, page 92.

Solvent Compounds. Magnus vapor cleaner used in steam or vapor cleaning combines the principles of soap washing with solvent cleaning. Hydralene, another cleaning compound, is soluble in kerosene or other petroleum distillates in all proportions without separation or loss of homogeneity. Brief references only. *Aero Digest*, November, 1938, page 92.

Meteorology

Turbulence and Aerial Navigation in the Substratosphere. V. Mironovitch and A. Viaut. Conditions existing in general at the base of the stratosphere are discussed. Advantages of flights at high altitudes are considered perhaps less important than the inconveniences following from the turbulence and from the speeds of the winds, near the disturbances, at altitudes of 8 to 15 km. Characteristics of the tropopause, deviations from average conditions or disturbances at the base of the stratosphere, and disturbances in the upper part of the troposphere are taken up.

During the cold seasons the northern and western parts of the Atlantic ocean are frequently invaded by very cold arctic air which descends at least to the 40th parallel. Because of the very rapid decrease in pressure with altitude in cold air, the depressions are brought out in the upper part of the troposphere. In that case the tropopause descends frequently to altitudes of 7 km. Winds which result on both sides of the tropopause can exceed 250 km./hr. as far as the latitude of the 40 N parallel, over about 4000 km., the number of disturbances being on an average two at a time between the United States and Europe and the average diameter of each being about 2000 km.

Transatlantic substratosphere flights can therefore only be carried out on days where the network of soundings of temperature at altitude over the ocean is sufficient to construct maps of pressure and pressure variations at altitudes of 5, 10, and 15 km. *L'Aéronautique*, October, 1938, pages 202–206, 5 illus., 1 table.

Engine Design and Research

Fuel Supply Systems in Aircraft. E. W. Knott. Prevention of vapor lock, and effect of altitude conditions in horizontal fuel pipes in which there is a suction head. When taken to conditions equal to 6000 meters the fuel column became completely ruptured and pump failed to function. Results of tests made by Établissements A.M. in France are discussed and shown in photographs. Tests taken in flight by insertion of glass tubes in the fuel feed system have confirmed the formation of vapor. Heating of pumps, case of an airplane taking off with fuel at 160°C. and climbing to 10,000 ft. in 5 min., location of fuel pumps, and remotely operated pumps are taken up. Hobson compressed-air-operated fuel pump is described and illustrated. *Flight, Aircraft Engr. Sup.*, July 28, 1938, pages 45–48, 8 illus.

Who Invented Cooling under Pressure? In 1932 C. Waseige pointed out the advantages of this solution to the problem of cooling liquid-cooled aircraft engines, and various Farman engines have been cooled with radiators operating under 2 kg. of pressure which raised the boiling point of the water to 120°. Abstracts of two papers by C. Waseige, one given in June, 1932, and the other in November, 1933. *Les Ailes*, October 6, 1938, page 7.

Aero Motors—Their Future Development. F. R. Banks. Engines of at least 2000 hp. within five years and of 4000 hp. in five or ten years' time are forecast. Not less than 24 cylinders, single sleeve valves, gasoline injection (perhaps), two-speed and/or two-stage superchargers, and exhaust turbo-blowers, particularly for substratosphere flying are predicted. Liquid-cooled engines may return to the commercial field, particularly for powers in excess of 2500 hp. Whole powerplant and cooling equipment must be arranged to be removed with a minimum of trouble. Napier H engine is considered a promising arrangement of cylinders for larger engines.

U. S. Army Air Corps work on gasoline injection and difficulties in application are mentioned. German development of gasoline injection for most of the later engines, and both German and American methods tried are taken up. Discussion also includes mechanical problems in arrangement of cylinders, advantages of sleeve valves, and difficulties and advantages of compression-ignition engines. Setting of the baffle plates of the latest Bristol Mercury to "force the air to stick to the sides of the cylinders," and the exhaust ring which forms part of the cowling are illustrated. *Aeroplane*, November 9, 1938, pages 556–558, 3 illus.

Determination of Altitude Performance of Aircraft Engines on the Basis of Performance Measurements under Ground Conditions. J. Zeyns and H. Caroselli. New method of conversion for determining altitude performance from results of tests on the ground. Method is the result of evaluation of numerous measurements which have been taken on the engine altitude test stand of the D.V.L. to determine the behavior of new Otto aircraft engines under altitude conditions. Results of comparative tests verify the value of the new method and fix the validity range of well known methods of conversion.

Discussion covers: subdivision of performance; power loss; determination of useful output above full-pressure altitude and of performance distribution below this altitude; effect of temperature on performance and on pressure behind the supercharger; effect of exhaust back pressure on performance; influence of control periods; and test procedure. *V.D.I.*, November 5, 1938, pages 1289–1296, 19 illus., 5 equations.

High Output of Aircraft Engines. E. Vohrer. Gradual progress in the high output of aircraft engines in recent years. Development of present-day engines for higher output; thermodynamic possibilities for increased life; method of high take-off output; various mixture formation processes and their influence on performance, economy, and reliability of operation; and special problems. *Luftwissen*, October, 1938, pages 357–367, 17 illus., 1 table.

Quantitative Analysis of Heat Transfer in Engines. R. N. Janeway. Method of evaluating coefficients of heat transfer from the gases to the internal engine surface is presented in the belief that it yields values reasonably close to the truth. Calculated data of heat loss from gases to cylinder surface, provided by the analysis given, makes it possible to estimate the temperature distribution over the surface, together with the relative importance of metal conductivity and convection from walls to water in dissipating the heat. Piston-head temperature is also considered. *S.A.E. Jour. (Trans.)*, September, 1938, pages 371–380, 11 illus., many equations.

The Single Sleeve as a Valve Mechanism for the Aircraft Engine. A. H. R. Fedden. Paper, and discussion by A. Nutt, F. C. Mock, A. T. Gregory, A. T. Colwell, S. D. Heron, V. C. Young, and C. Kemper. *S.A.E. Jour. (Trans.)*, September, 1938, pages 349–362 and (disc.) 362–365, 35 illus., 1 table.

Supercharger Installation Problems. A. L. Berger and O. Chenoweth. Paper and discussion by A. Nutt and S. R. Puffer. *S.A.E. Jour. (Trans.)*, November, 1938, pages 472–484, 22 illus.

Wear Reduction of Valves and Valve Gear. A. T. Colwell. Factors affecting rate of wear of valves and valve gear, and reasons for the recent marked improvements in the life of aircraft valves. Surface finish developments are described that were designed to decrease initial rate of wear. Ten means of getting close to initial clearance are outlined. Progress of work in three laboratories on surface treatments is reported. Relative amount of wear with various material combinations is compared. *S.A.E. Jour. (Trans.)*, September, 1938, pages 366–370, 6 illus., 3 tables.

Engine, Fuel, and Lubricant Testing

Fuels for Aircraft Engines. F. Suber. Present status of fuel research in Germany, and test methods and their evaluation, including characteristics of engines for determining detonation of fuels. Aircraft engine fuels for mixture intake as well as for fuel injection and spark ignition are considered.

Discussion covers: review of the development of fuel testing; present status of testing fuels in the Otto engine and small test engines; possibility of estimating physical-chemical test methods; comparison of requirements for aviation gasoline in Germany and other countries; and physical-chemical tests including specific gravity, refraction, boiling point, vapor pressure, resistance to cold, wax formation, corrosion, tetraethyl lead, and heating values.

To meet present requirements an engine test method is needed which is not restricted, as in the case of octane number determination, to testing under fixed test conditions, but which should consider various pressures, temperatures, and stresses in the case of a given fuel-air ratio. *Luftwissen*, November, 1938, pages 320–330, 8 illus., 3 tables.

Hi-Duty Spark-Plug Testing. A. L. Beall and L. M. Townsend. Preliminary single-cylinder engine test method for spark plugs evaluates resistance to pre-ignition. Tests for the method were made on liquid-cooled and aircooled single-cylinder test engines. Operating conditions were selected with regard for satisfactory performance plus the ability to heat the spark plug. A large number of spark plugs were re-run several times to check the reproducibility of the test method. Full-scale engine type test, ground fouling and flight fouling tests, and a starting-ability test are recommended as well as bench tests at intervals and measurement of electrode corrosion and wear as a check on probable useful life and ability of the spark plug to measure up to requirements of flight service. *S.A.E. Jour. (Trans.)*, November, 1938, pages 465–471, 8 illus., 3 tables.

Knock Testing—In the Laboratory and in Service. G. Edgar. Paper and discussion by J. O. Eisinger. *S.A.E. Jour.*, September, 1938, pages 7–12 and 17–20, 5 illus.

Proposed Method of Test for Ignition Quality of Diesel Fuels. C. F. R. Diesel-fuel testing unit and proposed method of test intended for determining ignition quality of Diesel fuels in terms of an arbitrary scale of cetane numbers. Description of apparatus and procedure. Proposed method is under jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. *S.A.E. Jour. (Trans.)*, November, 1938, pages 453–454, 464, 484.

Siemens Electrical Measuring Apparatus. Siemens remote-controlled tachometer measures the voltage produced by a permanent dynamic machine, coupled with the shaft, depending on r.p.m. Photographs and brief mention also for the following Siemens equipment: telephone for noisy rooms permitting good hearing at 115 phons; navigation compass with electric control; device consisting of four indicators for four engines, indicating temperature and pressure for right and left engines and thus detecting any interference; pilot's helmet with two telephone receivers; and a suspended amplifier. *Luftwissen*, October, 1938, pages 377–379, 9 illus.

Test Methods for Engines under Altitude Conditions. Panetti. Altitude engine test stand described was built in the Royal Polytechnic Institute for Aeronautical Research at Turin. Wind tunnel and the air conduction, exhaust-gas, cooling and electrical installations are discussed and illustrated. *Luftwissen*, October, 1938, pages 375–376, 5 illus.

A Torque-Reaction Test Stand. W. Kleinsorge. Evolution of the standard torque-reaction test stand, and description of the stand for air-cooled and water-cooled aircraft engines which was developed by Fahrzeug und Motorenwerke, Breslau, to the order of the German Air Ministry. Stand is fully enclosed in a streamlined cowling. Engine fulfills following requirements concerning vibration: elastic absorption of engine torque vibration, with adjustable damping to enable range of critical engine speeds to be displaced relative to those of oscillating frame of test stand, and elastic absorption of propeller vibration and of transverse engine vibration with adjustable damping. *Aircraft Engineering*, November, 1938, pages 344–345, 5 illus.

Engines

The 90 Hp. Gipsy Minor. Main bearing caps are incorporated into the top cover in the DeHavilland D.H. Gipsy Minor 90-hp. four-cylinder inline inverted aircooled engine and crankcase has exceptional stiffness. Valves are arranged transversely instead of on the longitudinal centerline. Incoming cold air is directed immediately onto the exhaust valves. As a result of the modification of the valve gear, shape of the cylinder head has been changed. Long detailed description with photographs and cutaway and other drawings. *Aeroplane*, November 2, 1938, pages 534–536, 7 illus. *Flight*, November 10, 1938, pages 424f–424h, 425, 7 illus.

Britain's Aero Engines. Aircraft engines produced by 16 British companies are described, some in great detail. The larger types include: Alvis Leonides 9-cylinder radial; Armstrong Siddeley Genet Major and Cheetah X (long description) and two-speed supercharging of the Tiger VIII; Aspin rotary combustion chamber (few details); Bristol Pegasus and Mercury series (long description, covering two-speed supercharger of the Pegasus XVII and XVIII, sleeve-valve claims, and construction as well as references to recent Aquila, Perseus, and Hercules); DeHavilland Gipsy Major I and II, and Minor; Napier Rapier VI, Dagger III, and Dagger VIII; and Rolls-Royce Merlin (description applying to all current models, excepting the Merlin I, brief references to a Merlin VIII with medium-altitude supercharger, and a Merlin X with two-speed supercharger which will be installed in the latest type of Armstrong-Whitworth Whitley bomber, and photographs comparing the Merlin II and Kestrel XVI).

Table gives characteristics and performance data for engines described as well as for the Tiger VIII and XII, Gipsy XII, Kestrels XIV, XV, XVI (two versions), Pegasus series, Aquila, and Hercules, and for a number of engines for light airplanes. *Flight*, November 3, 1938, pages 384–392, 392a–392d, 18 illus., 1 table.

Diesel Company Formed. Trans-America Aircraft and Motor Company, recently incorporated in Buffalo, N. Y., will start production soon on an experimental Diesel aircraft engine designed to deliver 164 hp. and weighing about 200 lb., according to C. A. Balton, designer of the engine. Brief reference. *Aero Digest*, November, 1938, pages 19–20.

The Improved Dagger. Improved Napier Dagger Series VIII engine has successfully passed its 100-hour type test. Larger double-entry supercharger, increased cooling-fin area, complete ignition screening, provision for a D.H.-Hamilton constant-speed propeller, S.U. carburetor with automatic mixture control, and electrically-energized inertia starter, nose cowl, and air chutes are included. Maximum power 1000 hp. at 8750 ft. and 4200 r.p.m. with 5 lb. boost. Take-off power 955 hp. at 4200 r.p.m. with 6 lb. boost. Climbing sea-level power 845 hp. at 4000 r.p.m. with 4 lb. boost. Maximum cruising power 770 hp. at 3600 r.p.m. with 3½ lb. boost. Brief note.

Second brief note refers to the Pixie four-cylinder inline 50-hp. engine. *Flight*, August 4, 1938, page 112, 3 illus.

New Diesel Aircraft Engine Proposed. Two-stroke 18-cylinder two-row radial Diesel engine designed by E. T. Rodgers is designed to give a normal output of 2000 hp. at 1600 r.p.m. with a maximum for take-off of 2250 hp. at 1750 r.p.m. Pilot charge of about 20 percent of the total is to be injected at 60° b.t.c. and remainder at 20° b.t.c. Air intake is controlled by a single sleeve valve per cylinder and exhaust by an oscillating valve in the upper part of the cylinder, motion being transmitted to the latter valve through the former. Air is taken in through ports at the bottom of the stoke, while exhaust takes place through eight exhaust ports in the cylinder. Brief note. *Automotive Industries*, November 12, 1938, pages 630, 658.

Performances of the Daimler Benz D.B.60. Twelve-cylinder inverted aircraft engine of 33.9-liter cylinder capacity and medium supercharging develops 1050 hp. at take-off. This is also the power at 4000 meters for the type with full supercharging obtained with 87-octane fuel. Compression ratio 6.5 to 1. Weight 550 kg. Few details. *Les Ailes*, October 20, 1938, page 7.

Ranger Engine Fifty-Hour Full-Throttle Non-Stop Test. Condition of engine parts after test is described in great detail with measurements made and comparison of inspection characteristics of new oil and that removed from the engine after test. Fuel and oil consumption is given. A Model 6-140 6-cylinder engine rated 165 hp. at 2450 r.p.m. and weighing 347.5 lb. (dry) was taken from the production line, furnished with a 4-bladed test club, given a 50-hr. full throttle run. Esso Aviation gasoline and Esso Aviation Oil 120 lubricant were used. *Aero Digest*, November, 1938, pages 71–72, 102, 5 illus., 3 tables.

Parts and Accessories

Chandler-Groves Carburetor. Nonicing carburetor installed on the Wright Cyclone G-100 series engines has automatic mixture control and an automatic accelerating pump. Chamber is walled on two sides against which fuel within exerts pressure. Description. *Aero Digest*, November, 1938, page 92, 3 illus.

Electric Control of Injection Pumps. Fuel injection pump operates either with gasoline or heavy oil, the fuel is introduced directly into the combustion chamber (or indirectly into the induction manifold) and injection of the combustible is developed with short delay. Renault and Marchand-Stuart patents for fuel pumps and their electric control are described and illustrated (the Renault patent being dated 1923). Reference only is made to the work being undertaken in the United States by the Bendix company for adapting a Cyclone G-101 of the Navy to injection of gasoline, attaining a fuel consumption of 165 gr./hp.-hr. Mention is also made to work undertaken by M. Lauret, Citroën, and P. Dumanois in France. *Les Ailes*, October 20, 1938, page 8, 3 illus.

New Developments in High Speed Diesels. P. M. Heldt. Development work on aircraft Diesel engines in Germany, England, and principally in France is discussed in the latter portion of the article. Coatalen four-stroke 12-cylinder vee liquid-cooled 600-hp. Diesel aircraft engine having a common-rail injection system, the Clerget 14-cylinder four-stroke two-row radial Diesel under development in a government engine plant, and the C.L.M. 6-cylinder double-piston 450-hp. engine are described and drawing of the Coatalen engine shown.

In the part devoted to automotive Diesels, the Saurer combustion chamber, injection nozzle, automatic injection-timing device, a special electric type of engine indicator for use in Diesel research, and a pressure chamber for study of injection phenomena are described with drawings. German Diesel engine for cross-country type of army trucks is also described in detail and Diesel rail cars in Germany are discussed. Concluded. *Automotive Industries*, November 26, 1938, pages 698–705, 14 illus.

"Heat-Formed" Piston Rings. Heat-forming production process for rings was developed by the Wellworthy Piston Rings Company in cooperation with aircraft-engine manufacturers. Rings are manufactured from centrifugally cast pots, constrained to a definite shape on a special mandrel, and heated in an electric furnace for a predetermined period. These rings are said to possess superior resistance to loss of tension under heat. Few details. *Flight*, July 28, 1938, page 52.

A Matter of Valves. C. G. Grey. Eight stages in the manufacture of the K.E. 965 valves in the plant of Kayser, Ellison and Company are illustrated in photographs and discussed. These valves are used in Rolls Royce, Bristol, Armstrong-Siddeley and DeHavilland engines. Production of alloy steels for special engine parts is also described. *Aeroplane*, November 9, 1938, pages 577–579.

Aircraft Radio

Aero Radio Digest. Sperry-RCA automatic radio direction finder. Western Electric Model 27A ultrahigh-frequency receiver intended for reception of various marker beacons. Learadio ARC-6 automatic direction finder. Ranger Neobeacon visual radio-range course indicator which can be used with any beacon receiver. Taylor Airphone transceiver (combined transmitter and receiver) intended primarily to fulfill requirements of Class A aircraft, for airport traffic control and two-way communication. I T & T chart of radio frequency allocations made in accordance with revisions decided upon at the International Telecommunications Conference. Descriptions of equipment and few details of the latter. *Aero Digest*, November, 1938, pages 95–96, 6 illus.

Automatic Fix. Continuous position indication is provided by a combination of D/F receivers in the Roberts-McGillivray position finder. Two loop aerials placed in the fuselage are tuned in to two different broadcast stations, and bearings obtained automatically laid off on a chart. Receiver is connected to the loop and also to a fixed aerial to give positive indication. Telephones are used for station identification. Electric relay is employed in the output circuit of the receiver to connect a battery to an electric motor which turns the loop and automatically stops when the loop has been lined up. Working principles and practical experiments are discussed. *Flight*, October 27, 1938, pages 377–378, 1 illus.

The Hazards of Homing. Criticism of the Croydon airport control in anding airplanes. The American radio-range system is considered to have the advantage in that its marker beacons give the pilot his ground speed very accurately and he can make the necessary changes easily. Navigation system used in Europe with two-way radio and bearings require more work and may be unhandy when radio traffic is heavy in bad weather. *Aeroplane*, November 2, 1938, pages 538–539, 1 illus.

Ultra-High Frequency Radio Receiver Developed. First ultra-high-frequency radio receiver capable of picking up signals ranging from 60 to 132 megacycles in frequency has been developed by P. D. McKeel of the Civil Aeronautics Authority. New receiver uses sections of coaxial lines for the radio frequency and oscillator tuned circuits in place of the standard coil and condenser. Brief reference. *Science News Letter*, November 5, 1938, page 297.

Problem of Radio Navigation for Aviation. E. Kramar. Present status of various radio navigation methods, and difficulties still to be solved. Horizontal and vertical navigation, and their combination in instrument landing methods, as well as protection against collision in the air are discussed. *Luftwissen*, October, 1938, pages 369–374, 6 illus.

Aeronautical Industry and Production

The Four Winds. Holland imported 2580 tons of aircraft and parts valued at £226,223, during the first six months, compared with 1840 tons (£223,889) in that period of 1937. Brief reference. *Flight*, August 11, 1938, page 125.

The Ancillary Industry. An "easy-reference" encyclopedia of over 400 firms that make their contribution to British aircraft manufacture and operation, including an index to products and index to firms and photographs of products. *Flight*, November 3, 1938, pages 392e–3921, 393–408, 36 illus.

Chandler-Evans to Make Accessory Products. Chandler Evans Corporation was recently formed to manufacture and develop a line of aircraft-engine accessories. Production will start on Chandler-Groves nonicing carburetor and on a line of aircraft and Diesel fuel pumps. Brief note on organization. *Aero Digest*, November, 1938, page 19.

Company Activities. Activities of the Aeronca, Brewster, Douglas, Fairchild, Lockheed, Martin, North American, Piper, Ryan, Seversky, Stearman, Vultee, Waco, and Wright companies. *Aero Digest*, November, 1938, page 20.

Backlogs. Despite record deliveries, reports from aircraft manufacturers indicate new contracts are more than sufficient to maintain the industry's backlog at well over $100,000,000. Note on backlogs of various companies. *Aero Digest*, November, 1938, page 42.

Exports at $48,693,213. Exports of American aircraft, engines, and aeronautical equipment during the first eight months attained a valuation 106 percent better than that for the same period a year ago and 23 percent more than for the entire year. Exports included 582 airplanes and 894 engines. During August most business was done with the Netherlands Indies (10 aircraft, 8 engines and $177,066 worth of parts and accessories). Short note giving also number of aircraft imported by other countries, and chart comparing 1938 with 1937. *Aero Digest*, November, 1938, page. 37.